GSA TODAY

THE GEOLOGICAL SOCIETY
OF AMERICA®

VOL. 29, NO. 3–4 | MARCH-APRIL 2019

Holes in the Bottom of the Sea: History, Revolutions, and Future Opportunities

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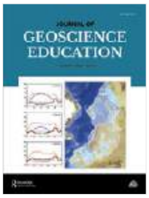

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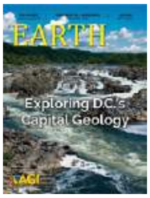

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MARCH-APRIL 2019 | VOLUME 29, NUMBER 3–4

GSA TODAY

GSA TODAY (ISSN 1052-5173 USPS 0456-530) prints news and information for more than 22,000 GSA member readers and subscribing libraries, with 11 monthly issues (March-April is a combined issue). *GSA TODAY* is published by The Geological Society of America® Inc. (GSA) with offices at 3300 Penrose Place, Boulder, Colorado, USA, and a mailing address of P.O. Box 9140, Boulder, CO 80301-9140, USA. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of race, citizenship, gender, sexual orientation, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

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SCIENCE

Cover: International Ocean Discovery Program (IODP) ships (left to right): the *Chikyu*, a riser-equipped platform coring in the western Pacific; the *JOIDES Resolution*, which recovers cores throughout the ocean; and a Mission Specific Platform (MSP) drilling vessel. Dotted lines—representative depth. Left: Methanogenic microbial communities recovered by the *Chikyu* during 2012 Expedition 377, Site C0020, more than 2 km (1.25 mi) beneath the sea floor in a Miocene coalbed 80 km (50 mi) off of the Shimokita Peninsula, Japan. Center: Paleocene–Eocene Thermal Maximum cores recovered by the *JOIDES Resolution*. Left core is from Site 1209, Shatsky Rise, Pacific, taken in 2387-meter-deep water (mbsl). Right core is from Site 1262, Walvis Ridge, South Atlantic, taken at 4755 mbsl. Color change shows carbonate dissolution. Right: MSP Expedition 364, Site M0077, cored through the rim of the Chicxulub impact crater. Shown is suevite that contains clasts and melted rocks. Photo credits: left: JAMSTEC/IODP; center and right: IODP. See related article, p. 4–11.

THE GEOLOGICAL SOCIETY OF AMERICA®

Holes in the Bottom of the Sea: History, Revolutions, and Future Opportunities

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ABSTRACT

No other international scientific collaboration has contributed as much to our knowledge of Earth processes as scientific ocean drilling (SOD). These contributions include geophysical surveys, core samples, borehole well logs, and sub-seafloor observatories. After more than half a century, involving thousands of scientists from around the world, SOD has been instrumental in developing three geoscience revolutions: (1) plate tectonics, (2) paleoceanography, and (3) the deep marine biosphere. Without SOD, it is unlikely that our current understanding of Earth processes could have developed. Building upon prior scientific results, the current science plan is guided by four interlinked themes: Planetary Dynamics, Climate and Ocean Change, Biosphere Frontiers, and Earth in Motion. SOD has also been a leader in international collaborations and the open sharing of samples, data, and information. Results from SOD expeditions are open access and available online. Almost 2.5 million samples have been taken from over 360 km of core located in three repositories. Today about half the members of scientific teams, including co-chief scientists, are women. This program is needed in the future for geoscientists to continue exploring our planet to understand how it functions and to create predictive models.

INTRODUCTION

Scientific ocean drilling (SOD) celebrated its 50th birthday in 2018. As of December 2018, 283 expeditions (formerly called legs) have been completed and >1600 sites have been drilled (see Fig. S1 in the GSA Data Repository[1]). These sites represent <0.0005% of the ocean floor, yet have provided essential information about plate tectonics, ocean chemistry, evolution, life in harsh environments, and climate change.

Scientists from across the world have benefited from and contributed to the program. Geophysical site survey data, cores, and associated information are available to the global scientific community to study and sample. More than 1000 international scientists, ranging in age from early career to retired, are proponents on active proposals for upcoming drilling.

This article, by no means comprehensive, highlights parts of the history and a few major discoveries of SOD. More complete histories are available in *Ocean Drilling: Accomplishments and Challenges* (National Research Council, 2011), *Earth and Life Processes Discovered from Subseafloor Environments: A Decade of Science Achieved by the Integrated Ocean Drilling Program (IODP)* (Stein et al., 2014), and Koppers et al. (2019). GSA Data Repository Table S1 (see footnote 1) provides URLs to detailed, preliminary information for all SOD expeditions and legs, including co-chief scientists, sites cored, and year.

HISTORY

Pre-JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling)

SOD may be said to have originated with the International Geophysical Year (1957–1958), and an organization with the unlikely name American Miscellaneous Society (AMSOC). AMSOC included men at pivotal positions at oceanographic institutions, oil companies, the Office of Naval Research, and the United States Geological Survey. Bascom (1961) provides details about AMSOC and the development of their discussions about SOD. Walter Munk (Scripps Institution of Oceanography [SIO]) and Harry Hess (Princeton University), both AMSOC members, proposed to drill a deep hole to sample Earth's mantle below a zone of seismic velocity change, the Mohorovicic Discontinuity (Moho): "Project Mohole."

The National Science Foundation (NSF) may have been in favor of the project, because the 1957 International Union of Geodesy and Geophysics Resolution 11 recommended that the Moho be drilled. The Soviet Union said they had the equipment and were looking for a place to drill (Bascom, 1961). They had just launched the Sputnik satellite. Their technological advance alarmed many Americans and spurred investment in U.S. science and technology.

Despite the difficulties of SOD, AMSOC, with NSF funding, took on the challenge. Many technological improvements were necessary for such a project: a drilling platform that could hold station in deep water and under different wave and wind conditions (dynamic positioning), a way to retrieve cores through drill pipe so that the drill pipe could stay in place, and a sturdy drill bit that could operate for days, even weeks. The first drilling was accomplished in 1961 with the barge, *CUSS I* (Continental, Union, Shell, and Superior). Unfortunately, after a promising start, organizational difficulties, and loss of political support, Project Mohole, deemed too expensive, was abandoned in 1966 (Hsü, 1992).

The *Glomar Challenger*

Not everyone agreed that drilling a single deep hole in igneous rock was the best initial SOD research objective. In 1962, Cesare Emiliani (University of Miami) proposed that a drilling vessel be

GSA Today, v. 29, https://doi.org/10.1130/GSATG380A.1.

[1] GSA Data Repository item 2019051, Table S1 and Figures S1–S7, is available online at www.geosociety.org/datarepository/2019.

deployed to core continuously through deep-sea sediment (project LOCO, LOng COres). Maurice Ewing (Columbia University, also a member of AMSOC) supported obtaining multiple long cores, stating, "The entire record of terrestrial conditions from the beginning of the ocean is there in the most undisturbed form it is possible to find anywhere—and the dream of my life is to punch that hole 2000 feet deep and bring the contents to the lab to study them" (Gray, 1956).

Thus, simultaneously with Project Mohole, a different kind of program was planned. Five U.S. oceanographic institutions established JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling). In 1965, using dynamic positioning, fourteen holes were cored in the eastern Atlantic Ocean on board the *Caldrill I.* The results convinced the scientific community of the value of multiple holes throughout the ocean. In 1967, Global Marine was contracted to design a ship expressly for the purpose of SOD. With SIO as the prime contractor, the Deep Sea Drilling Project (DSDP), using the Glomar Challenger, was launched (Bascom, 1961).

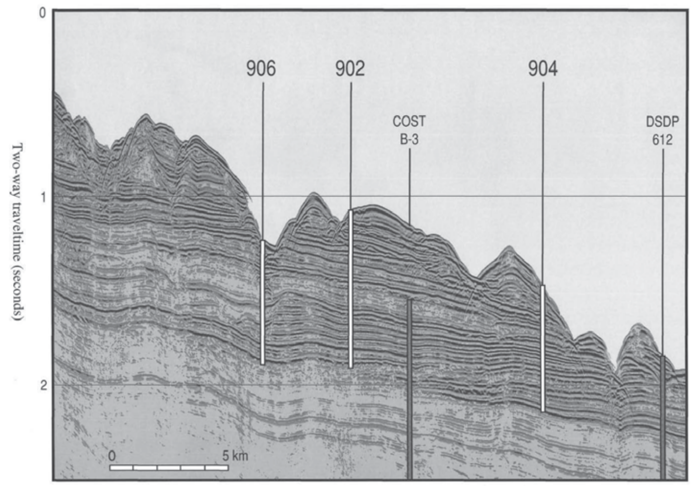

Figure 1. Multichannel Seismic Line 1027 in Baltimore Canyon, used to locate the best sites (902, 904, and 906) during Ocean Drilling Program Leg 150 (Mountain et al., 1994). Cored intervals are shown in white. Also shown are the locations of Deep Sea Drilling Project Site 612 (Leg 95) and the Continental Offshore Stratigraphic Test (COST) B-3 well. The COST B3 well was used to establish first-order age and facies successions. These sediments were cored to establish a history of sea-level variations along the mid-Atlantic U.S. continental margin. Mission-specific drilling platform Expedition 313 continued the coring in modern water depths of 30–35 m and recovered nearshore and onshore sediments deposited during Neogene changes in global sea level.

Deep Sea Drilling Project (DSDP, 1968–1983)

By 1968, several seminal papers on plate tectonics (e.g., Hess, 1962; Vine and Matthews, 1963; Wilson, 1966) had been published. These papers were based on sparse data, leaving many unconvinced. Interpretation of marine magnetic anomalies (e.g., Pitman et al., 1968) and better earthquake data (e.g., Isacks et al., 1968) provided additional support for this theory. For many, final confirmation came from SOD.

As with Project Mohole, whose objective was seismically defined, Leg 1 of the Glomar Challenger and all subsequent expeditions have used seismic surveys to determine the ideal place to drill for science (Fig. 1) and for safety reasons, such as avoiding overpressured hydrocarbons. Leg 1's objectives in the central Gulf of Mexico were clear; identify the cause of the reflectors on the seismic profiles, especially the domes and knolls on the deep-sea floor, and recover the oldest ocean sediment. Leg 1 of DSDP was a success. The domes were salt diapirs. The oldest sediment was Jurassic, much younger than expected.

Seven days later, Leg 2 began coring across the Atlantic. The scientific party of eight included two female micropaleontologists, Catherine Nigrini (SIO) and Maria Bianca Cita (Instituto di Geologia, Universitá di Milano, Italy). This began a tradition of international participation that was formalized in 1975: five countries (Federal Republic of Germany, France, Japan, the Soviet Union, and the UK) became contributing international partners in the International Phase of Ocean Drilling (IPOD). Today, 23 countries are part of the IODP consortium, and women comprise about half of the science team.

Technological development continually improved drilling, coring, and logging. In 1970, the first re-entry cone was deployed (Leg 15, Site 146, Venezuelan Basin), allowing the drill string to be pulled, a new bit attached, and coring in the same hole to continue. This enabled the drilling of deep holes through sediment and into hard rock. In 1979 (Leg 64, Guymas Basin), the hydraulic piston core (HPC) was deployed for the first time (Fig. S2 [see footnote 1]). Today, the HPC and multiple offset holes at a single site are routine for paleoceanographic expeditions. This allows construction of complete "composite" stratigraphic records, essential for detailed paleoceanographic research (Figs. 2 and S3–S5 [see footnote 1]).

The *JOIDES Resolution*

Ocean Drilling Program (ODP, 1983–2003)

By the late 1970s, JOIDES began exploring alternative vessels. Major improvements in heave compensation and station-keeping ability offered better cores and an expansion of geographic areas that could be explored. More research could be accomplished with expanded laboratories and more scientists. The *SEDCO/BP 471*, an oil exploration vessel, was chosen, highlighting the advances in technology generated by the petroleum industry. Funding for the new program came from the United States and member countries. Texas A&M University was awarded the contract. The *SEDCO/BP 471* was converted to a scientific drilling vessel, the *JOIDES Resolution*, and on 11 January 1985 commenced operations. Unlike petroleum exploration, which relies heavily on well logs and cuttings to understand the geology of a location, SOD collects cores. For most JOIDES Resolution legs, a shipboard scientific party would analyze cores and document findings during two-month expeditions, working in two 12-hour shifts, seven days a week.

Integrated Ocean Drilling Program (IODP, 2003–2013)

Despite the capabilities of the *JOIDES Resolution*, critical locations remained

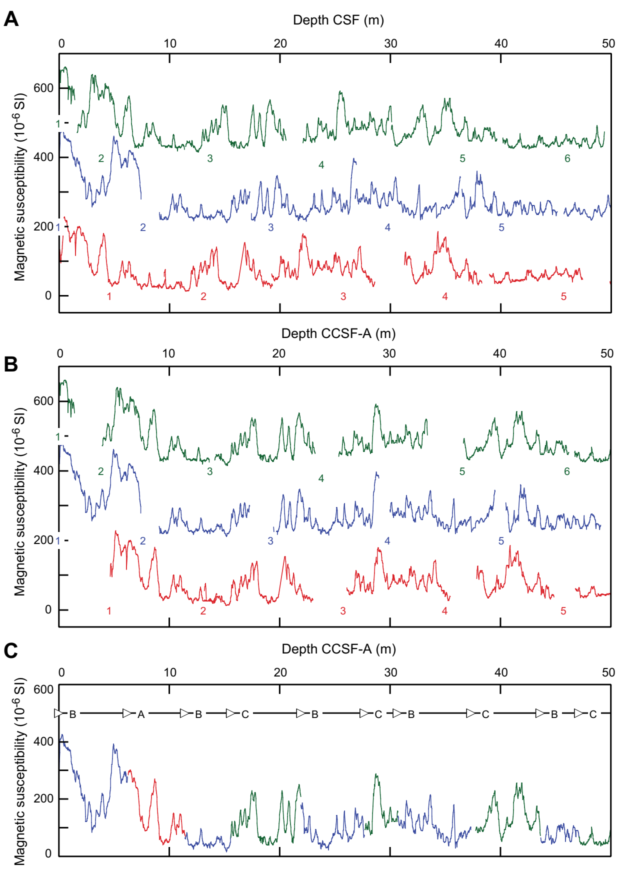

Figure 2. The tops and bottoms of cores are usually disturbed and there are often coring gaps between cores. To remedy this and create a complete stratigraphic sequence, a "composite" ideal core is created by splicing together data from different holes to so that coring gaps in one hole are filled with core intervals from an adjacent hole, trying not to use the tops and bottoms of cores. To generate a composite core depth below seafloor (CCSF-A) at least two or more holes are drilled at each site and each hole is slightly offset by depth from the other (Fig. S3 [see text footnote 1]). Hole core measurements, such as magnetic susceptibility and natural gamma ray, and/or split core images and lithologic changes from the different holes are aligned using distinguishing features, such as a sharp peak or a color change. (See Figs. S3–S5 for additional examples.) (A) Example from Site U1333, central Pacific, showing construction of a CCSF-A. In this example, magnetic susceptibility measurements from different holes are aligned by depth; Hole U1333A (red), Hole U1333B (blue), Hole U1333C (green). Numbers indicate the order of cores taken in the hole. (B) Depth-shifted cores on composite depth scale (CCSF-A [m]) aligning distinguishing features. (C) The magnetic susceptibility records the different holes that are part of the splice are shown by the hole color along the bottom. Along the top, core breaks (triangles) and hole designations are shown (from Pälike et al., 2010).

inaccessible. Without a riser system, with its casing and the ability to circulate mud and prevent blowouts, many thickly sedimented continental margins and subduction zones were out of reach. Locations at some high latitudes with ice and in very shallow water could not be explored. To meet these scientific needs, a new era of SOD began in October 2003. The riser-equipped, Japanese-built Chikyu, capable of drilling deep into heavily sedimented margins, and the mission-specific drilling platforms (MSPs) operated though the European Consortium for Ocean Research Drilling were added.

International Ocean Discovery Program (IODP, 2013–2023)

Today, there is a much broader understanding of the interconnections among Earth's spheres, and new fields of research have developed. Much has been learned about how Earth operates. But, the details necessary to reach the next level of understanding require interdisciplinary expertise, atmospheric scientists, computer modelers, and biologists. Achieving deeper knowledge has become more complex and requires a new approach. This broadly integrated approach is laid out in the present science plan: *Illuminating Earth's Past, Present, and Future* (IODP, 2011).

SOME SOD HIGHLIGHTS

SOD has been an engine for understanding Earth processes. Tens of thousands of papers have been published, some among the most highly cited in Earth science. Thousands of scientists from around the world, from undergraduates to emeritus, have been involved in the research, forming international collaborations extending beyond SOD.

Describing the results in a short paper is challenging and necessarily incomplete. Here, three areas where SOD contributed to major revolutions in our understanding of Earth are described: plate tectonics, paleoceanography, and the deep marine biosphere. These topics are intertwined. Clearly, plate tectonics impacts ocean and climate history, which in turn affects the deep biosphere; all are connected through carbon and water cycling. Future drilling will continue to enhance geoscientists' understanding of interconnected Earth processes from both a planetary and a human impact perspective.

Revolution #1: Plate Tectonics

In the ocean, plate tectonic knowledge has come from geophysical studies, submersible observations, and samples, drill cores, and instrumented boreholes to monitor in situ processes. As information leading to the wide acceptance of plate tectonics accumulated, one of the most convincing data sets came from DSDP Leg 3. "The most interesting finding from the paleontological studies is the correlation of paleontologic ages of sediments immediately overlying the basalt basement with ages of basement predicted by the sea-floor spreading hypothesis" (Maxwell et al., 1970, p. 445).

Below, briefly summarized, are some of the major results learned since Leg 3.

Rifted Margins (Also Called Passive Margins)

Continental rifting and ocean basin formation are central processes of plate tectonics and continue to be an important focus of SOD. This is an iterative process, with geophysical surveys identifying prime drilling targets and SOD providing the cores to determine the age and composition of specific reflectors. Primary influences on rift development are related to mantle composition, thermal structure, and tectonic stresses. This results in two end-member classifications, magma-rich and magma-poor (non-volcanic) margins.

Magma-rich margins were drilled during multiple expeditions (Legs 38, 81, 104,

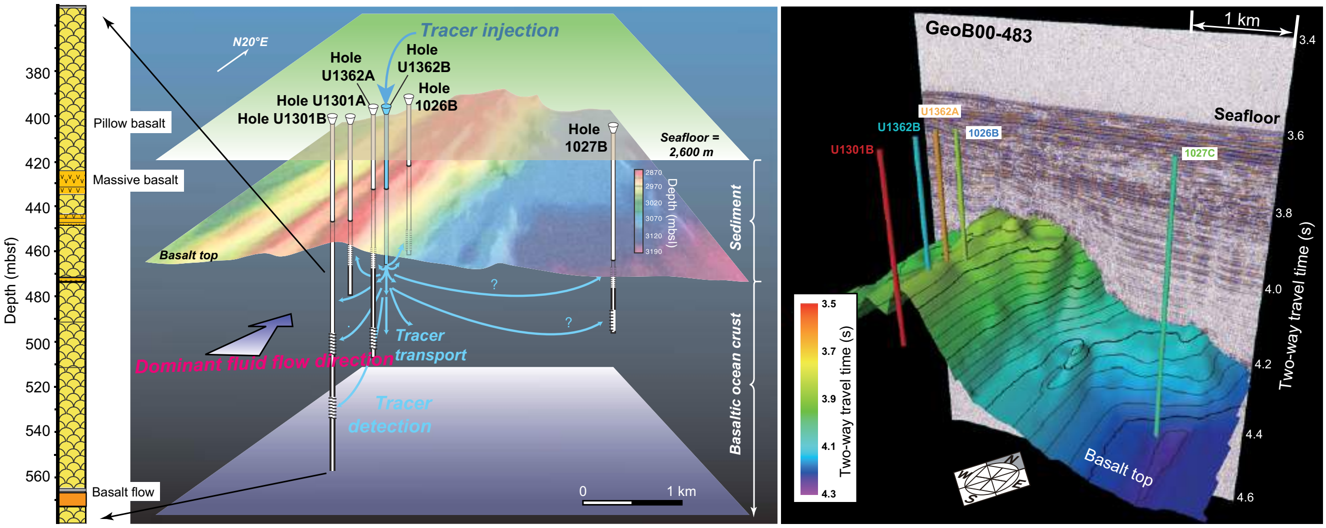

Figure 3. Schematic (not to scale) of borehole locations and experimental design for a tracer injection experiment conducted during and after Expedition 327 to investigate transport rates in the upper ocean crust. Boreholes observatories were placed in ~3.5–3.6-m.y.-old crust on the eastern flank of the Juan de Fuca Ridge. Thicker sections of the drill pipe indicate open intervals where tracer was injected or sampled. The stratigraphy of the upper volcanic crust at Hole U1301B is shown on the left. Main diagram modified from Fisher et al. (2011), and stratigraphic column is from Becker et al. (2013). Experimental results indicate very rapid tracer transport (meters/day), with most of the flow occurring in a small fraction of the rock (Neira et al., 2016). See Figure S7 for additional information (see text footnote 1).

152, 163) with segments along the East Greenland–Norwegian rifted margins (Fig. S6 [see footnote 1]), an area that constitutes part of the North Atlantic Igneous Province. An early surprise in drilling these margins was that some of the well-defined, seaward-dipping reflectors west of Norway consisted of subaerial extrusive basalts. Later, ^{40}Ar-^{39}Ar dating of volcanic rocks in southeast Greenland showed that the breakup evolution spanned ~12 m.y. (Tegner and Duncan, 1999).

Magma-poor margin drilling has taken place on the once contiguous Newfoundland-Iberian margins (Legs 47, 149, and 173, and Expedition 210), and in the South China Sea (Expeditions 349, 367, and 368). These expeditions, with sites carefully located along seismic lines, have recovered sediments, continental crust, a wide variety of igneous rocks, and even serpentinized mantle. Most recently, MSP Expedition 381 cored the Corinth Rift in the Mediterranean. There, a syn-rift sequence is accessible, allowing the fault and rift evolutionary history, including the deformation rates, to be determined.

Ocean Crust and Lithosphere

Understanding the composition and structure of ocean crust, how it varies, and how it is accreted is fundamental to understanding Earth's basic evolution. In the late 1970s, the structure of ocean crust gleaned from geophysical surveys, dredge hauls, submersible observations, and ophiolites was perceived as fairly simple: basalts on the seafloor were fed by sheeted dike complexes that emanated from a magma chamber where gabbro crystalized and accumulated over underlying mantle. There was, as there is today, discussion about the differences between fast and slow spreading and the distinguishing features of backarc basins. Now parts of the ocean crust have been sampled, boreholes instrumented, and geophysical and submersible observations collected. The ocean floor is much more varied and complex than the early models suggested.

Multiple expeditions at Hole 504B (Alt et al., 1996) and Hole 1256D (Wilson et al., 2006) in the eastern Pacific partially support the model of layered ocean crust, with basalts overlying sheeted dikes, which in their deeper parts contain lenses of gabbro. The structure and composition of the deeper crustal components was addressed at the Hess Deep Rift on the East Pacific Rise (Leg 147 and Expedition 345). There, the variety of textures and composition of the plutonic rocks was larger than expected.

In the Atlantic, where spreading is slower, investigators were initially surprised by the presence of serpentine mixed with basalts (Site 395, Leg 45). Many subsequent expeditions showed that mantle and lower crustal rocks, displaced upward along major normal faults, are integral components of slow and ultra-slow spreading crust. These faults are also conduits for hydrothermal fluids that lead to the formation of massive sulfide deposits as observed in the Trans-Atlantic Geotraverse hydrothermal field (Leg 158).

A critical component of modeling crustal accretion (and subduction) is understanding the role of hydrothermal circulation. To learn more about this plumbing system, many holes have been instrumented with circulation obviation retrofit kits (CORKs). CORKs seal off the borehole from the sea floor, allowing in situ measurements of pressure and temperature, and show the extent of fluid circulation in young ocean crust, which may be one of the most hydrologically active formations on Earth (Becker and Fisher, 2000). Advanced CORKs allow for additional measurements (e.g., seismometers and fluid sampling), ocean observatories, and experiments (Fisher et al., 2011; Figs. 3 and S7 [see footnote 1]).

Convergent Boundaries

Convergent boundaries (subduction zones) include island arcs, forearcs, backarc basins, and accretionary prisms. Processes at these plate boundaries are more likely to impact humans than any other component of plate tectonics, generating large earthquakes, explosive volcanoes, and tsunamis. The Chikyu has focused on the deeper portions of this plate boundary, especially in the Nankai Trough and Japan Trench.

Drilling has been essential in illuminating the origin and evolution of convergent margins. Not only are crust and sediment being subducted, but material from the overlying plate is scraped off by the underlying plate, termed subduction erosion. This process is ubiquitous at convergent margins, recycling material deep into the lower crust and mantle (e.g., Scholl and von Huene, 2009). Trace elements and isotopic tracers in volcanic rocks substantiate the subduction and hence chemical recycling of ocean sediments (e.g., Plank and Langmuir, 1993).

Crucial to the processes at subduction margins is illuminating the cause of large earthquakes, identifying what happens at the seismogenic zone when the release of pressure causes a major rupture. From cores and borehole measurements, variations in lithologies, fluids, pore pressure, and heat flow have been documented. These observations, in conjunction with dip angle, subducting seafloor topography, and results from ocean bottom seismometers, highlight this environment's complexity.

Multiple Legs (DSDP, ODP) and Expeditions (IODP) have focused on subduction zones and backarc basins. The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) on board the Chikyu is a multiyear project to core through a plate boundary in an active fault area. In addition to cores, it is providing the opportunity to monitor hydrologic and geodynamic properties of the subduction zone through borehole observatories. All of this information will help to develop models that describe subduction zone process and should allow geoscientists to better explain and predict earthquake behavior and tsunami generation.

Revolution #2: Climate and Ocean Change: Paleoceanography

The science of pre-Quaternary paleoceanography arguably did not exist when the Glomar Challenger set sail in 1968. The first International Congress of Paleoceanography took place in Zurich, Switzerland, in 1983, and the American Geophysical Union began publishing *Paleoceanography* (now *Paleoceanography and Paleoclimatology*) in 1986. Early paleoceanographic research, based on short cores, showed a marine expression of the Ice Ages recognized on land. Oxygen isotope records of foraminifera (Emiliani, 1957) documented more than the four previously identified Ice Ages and hinted at a cyclicity later tied to orbital forcing. Longer cores were needed to extend these records. Today, compilations of oxygen ($\delta^{18}O$) and carbon isotope values ($\delta^{13}C$) from calcite secreted by benthic foraminifera are essential for past climate reconstructions. Data compiled by Zachos et al. (2001), Lisiecki and Raymo (2005), and Cramer et al. (2009), include tens of thousands of analyses from hundreds of cores collected by many scientists over decades. These compilations and many new oceanographic proxies document long- and short-term climate change and rates of change. But the changes go far beyond "just" climate. SOD has allowed us to identify changes in ocean chemistry, better understand the effect of the asteroid impact at the K/Pg boundary, and, through continuous ocean records, better understand evolution.

All of these advances benefit from excellent resolution, provided by continuing developments in paleomagnetics, biostratigraphy, X-ray core scanners, and orbitally tuned age models. Early in SOD, holes were often spot cored. Then the community decided that holes generally should be continuously cored. After the advent of the HPC, higher resolution work became possible, but cores in a single hole do not provide a truly complete record. The top and bottom of each core is disturbed. Today, multiple, overlapping holes at a single site allow creation of a continuous composite core (Fig. 2). Here, highlights of two paleoceanographic achievements are briefly summarized.

Messinian Salinity Crisis

Leg 13 departed Lisbon, Portugal, in 1973 to explore the origins of the Mediterranean Sea and, in particular, to identify reflectors on seismic profiles. Coring the pervasive and prominent M-Reflector proved problematic. The problem was caused by the unexpected presence of gravel, which jammed the drill pipe, and salt (dolomite, gypsum, anhydrite, and halite), which was slow to impossible to penetrate. The M-reflector was caused by the top of a thick salt layer that accumulated in the late Miocene, 3 km below the surface of the Atlantic Ocean. The initial interpretation was that the Mediterranean dried up several times during the Messinian (Hsü et al., 1973). The details about the causes and extent of the desiccation and the role of tectonics have been debated ever since (Ryan, 2009). Additional drilling in the Mediterranean, with better coring capabilities and refinement of the areas to be drilled, is needed. Among the new IODP proposals is "The Demise of a Salt Giant," to examine the climate and environmental transitions during the terminal Messinian salinity crisis.

Paleocene–Eocene Thermal Maximum (PETM)

At the start of the ODP, no one knew about the PETM. This global warming event challenges our understanding of the carbon cycle and is discussed in more than 500 refereed papers. Its discovery led to identification of multiple "hyperthermal events" of lesser magnitude in the Paleocene–Eocene, thus a new view of climate instability in a greenhouse world. First identified in Site 690 (Leg 113, Weddell Sea, Antarctica), it was characterized by extinction of benthic foraminifera (Thomas, 1989). Stable isotope data told an incredible story, a rapid deep-sea warming combined with a massive negative carbon isotope excursion (Kennett and Stott, 1991) and—as later recognized—widespread deep-sea carbonate dissolution due to ocean acidification (Zachos et al., 2005). The details of this event are still debated, but the deep ocean warmed ~5–8 °C in a few tens of thousands of years, ca. 55.8 Ma (Mudelsee et al., 2014). Even in the Arctic Ocean, already ~18 °C, temperatures rose an additional 5–6 °C during the PETM (Sluijs et al., 2006).

Acidification and a $\delta^{13}C$ excursion were linked to a massive discharge of carbon. Calculating how much carbon was released depends upon the source and its isotopic composition. This has been highly debated and may be some combination of decomposing clathrates (Dickens et al., 1995), burning of organic matter (Kurtz et al., 2003), mantle-sourced volcanic CO_2, and interaction of magma with organic matter (Svensen et al., 2004; Gutjahr et al., 2017).

Revolution #3: Biosphere Frontiers: Deep Marine Biosphere

From its initiation, there have been serendipitous discoveries by SOD, but probably none was as unexpected as that of the deep biosphere. In the late 1980s, some researchers began to discover microbial activity in deep marine sediments (e.g., Whelan and Tarafa, 1986). This discovery didn't get celebrated the same way as the discovery of the hydrothermal vent communities a decade earlier. Yet these communities, invisible to the naked eye, contain abundant biomass. Just how much is a matter of debate; Kallmeyer et al. (2012) estimated there are roughly as many cells in marine sediment as in the ocean or in soil. Bar-On et al. (2018) refined the estimate to 77 Gt of carbon (~14% of biomass carbon) that reside in the deep subsurface, both land and marine.

Are they living cells? Metabolic rates of these communities are orders of magnitude slower than those on the surface and hence barely detectable (e.g., D'Hondt et al., 2002; Hoehler and Jørgensen, 2013). Unknown and critical to this discussion is determining the connections between the geobiosphere that humans inhabit and this barely explored marine world.

The accomplishments that have been made did not come easily. Even after samples are collected, there are challenges, such as characterizing bacteria that grow so slowly as to be virtually dormant. Despite the challenges, there is now access to this new world (Inagaki et al., 2015). Maybe fifty years from now geoscientists will be shocked at our ignorance about such a critical component of Earth processes.

Gas hydrates are also part of deep biosphere research. Several decades ago, they were inferred from bottom simulating reflectors (BSRs), a puzzling reflector that corresponded with the predicted base of the methane hydrate stability zone. First cored on Leg 67, sediment above the BSR indeed contained hydrates, and as the cores warmed and the gas expanded, the sediment left the core barrel and shot across the deck. Special pressure core barrels needed to be and were developed. Now scientists on the JOIDES Resolution have cored gas hydrates in many environments, especially on subduction margins. For example, scientists on Expedition 311 (Cascadia Margin) determined that most of the marine hydrate is caused by the microbial reduction of CO_2 within the hydrate stability zone (Riedel et al., 2010). Looking to the future, dissociation of hydrates might produce slope instability and the release of methane.

PRESENT (2013–2023)

Illuminating Earth's Past, Present and Future (IODP, 2011) describes four themes of focus for the current IODP. It highlights opportunities to use SOD to explore connections between Earth's spheres in ways that will help to further revolutionize geoscience. Each theme is briefly described in the following sections.

Planetary Dynamics (Deep Processes and Their Impact on the Earth's Surface Environment)

Plate tectonics is the driving force for Earth processes. Yet, despite decades of research, some of the most basic mechanisms are not fully understood. What is clear is that the seemingly different components of the Earth system are connected, and water and carbon are primary connectors. To understand these processes, geoscientists need samples from the surface sediment, through the ocean crust to the mantle. Although plate tectonics appears to be a fairly steady-state process today, it may not always have been so. For example, there is much to learn about the past emplacement of large igneous provinces, when massive amounts of mafic magma were discharged into the ocean and onto land, and abundant gases (CO_2, H_2S, and SO_2) were emitted into the atmosphere.

Climate and Ocean Change: Reading the Past, Informing the Future

The ocean ecosystem is changing in response to elevated atmospheric CO_2: it is becoming warmer, and the ocean is acidifying. The rate of modern changes may be unprecedented (except for asteroid impacts), but Earth has experienced similar perturbations in the past. The carbonate compensation depth has risen and fallen, and icebergs left rocky trails of their passage. Through examination of marine sediment cores, geoscientists can determine how the ocean (and ocean life) responded in the past. Collecting the detailed data necessary to better characterize past changes will help climate modelers better predict our future.

Biosphere Frontiers: Deep Life, Biodiversity, and Environmental Forcing of Ecosystems

The unexpected finding of microbial communities in the sea floor opens a wide variety of possibilities for exploration. Their very existence challenges our understanding of the minimal conditions necessary for life. Three major themes are being addressed: (1) sub-seafloor microbial communities; (2) the limits to life in the deep biosphere; and (3) community adaptation to a changing environment. This information will increase understanding of biodiversity and evolutionary paths on Earth and aid expectations for the existence of life in other parts of the solar system.

Earth in Motion (Geohazards)

An increasing human population, especially in coastal areas, puts more people in harm's way. This harm can come rapidly from earthquakes, tsunamis, volcanoes, and landslides. This is an area where borehole tools have a crucial role in furthering our understanding of the subsurface processes that cause these changes. Long-term, in situ data collection can monitor the conditions of earthquake generation and biogeochemical cycling, allowing the rate of the different components of these changes to be better understood and providing the data for more accurate modeling of these critical environments.

FUTURE (POST-2023)

Plans for the science program for the next phase of SOD are already under way as many critical questions remain. For example: How do subduction zones initiate and continents rift? How fast can sea level rise? How have marine microbial communities responded to past changes in ocean chemistry and temperature? This is an opportunity for geoscientists from many disciplines and countries to become involved in the continuation of an exciting international program that is critical to Earth science.

CONCLUSIONS

Although we have yet to drill through the Mohorovicic Discontinuity, SOD has radically changed and continues to change our view of Earth. Early SOD showed an unexpectedly young ocean and confirmed plate tectonics as the underlying mechanism for Earth processes. Recent SOD provides new information about elemental recycling and Earth history. Just as we learn more about outer space and the origin of the universe with better telescopes and planetary missions, we will learn more about our planet, the processes that drive it, and the origin of life as drilling technology improves. The intrigue continues as each seismic survey defines where to drill, each core sheds new light on Earth's past and helps predict its future, and borehole instrumentation provides in situ monitoring of Earth's processes.

ACKNOWLEDGMENTS

This article was considerably improved thanks to discussions with and reviews from B. Clement, S. D'Hondt, A. Fisher, J. Karson, J. McManus, E. Thomas, B. Tucholke, D. Royer, *GSA Today* editor G. Dickens, and two anonymous reviewers. Please share your favorite highlights of SOD in the GSA Member Community Open Forum at https://bit.ly/2KhR493.

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[2] Here, unless there is a specific figure or quote from a scientific ocean drilling volume, references to initial discoveries from Legs (DSDP and ODP) and Expeditions (IODP) are given only by their Leg/Expedition number. Table S1 (see footnote 1) provides links to a complete listing of Legs and Expeditions.

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Manuscript received 12 July 2018
Revised manuscript received 26 Nov. 2018
Manuscript accepted 8 Dec. 2018

Important Dates

Late March: Space request system opens (non-technical, social, and business meeting room requests)

Early May: Housing Open (Orchid Events is the official housing bureau for GSA 2019 Phoenix)

Early May: Registration and Travel Grant applications open

6 May: Space request deadline—fees increase after this date

25 June: Abstracts deadline

Early July: Student volunteer program opens

19 August: Early registration deadline

19 August: GSA Sections travel grants deadline

26 August: Registration and student volunteer cancellation deadline

28 August: Housing deadline for discounted hotel rates


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Photos from top: ©Visit Phoenix/Dennis Murphy/Dennis Scully, ©Visit Phoenix/Mark W. Lipczynski.

Meeting Location

Registration, technical programs, poster sessions, exhibits, and field trip departures will be at the Phoenix Convention Center (PCC), 100 N. 3rd Street, Phoenix, Arizona 84005, USA.

Hotel Information

The official GSA Housing Bureau, Orchid Events, will open for reservations in early May. The Sheraton Grand Phoenix will serve as GSA headquarters and the Hyatt Regency Phoenix is the co-headquarters hotel. Both hotels are located within walking distance of the Phoenix Convention Center (PCC). The GSA block includes seven hotels offering rates from US$159 to US$209 single/double occupancy (per night, plus tax). All hotels are within walking distance of the PCC.

Protect yourself: As the number of online hotel bookings continues to increase, so does the rate of booking scams. According to the American Hotel & Lodging Association, fraudulent websites con 2.5 million North Americans out of $220 million every year. Only use a trusted source to make your hotel reservation, and beware of anyone contacting you directly via email, phone, or fax. If you have any questions, please contact the GSA Meetings Department at meetings@geosociety.org. We will post information on our website regarding hotel reservations in mid-May.

GSA GeoCorps™ America Program

Fall/Winter 2019–2020 GeoCorps Opportunities to Be Posted 1 May 2019

GeoCorps provides geoscience opportunities on federal public lands. Project areas include a wide variety of topics, such as paleontology, hydrology, geohazards, caves/karst, GIS/mapping, and more.

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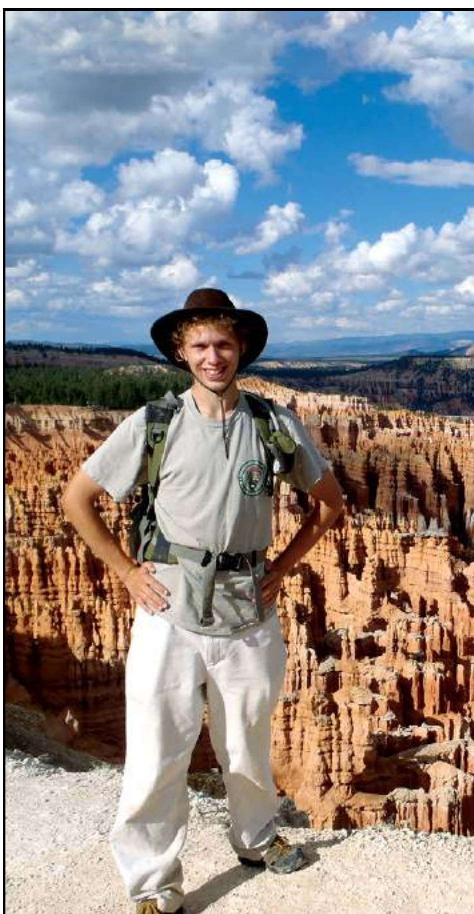

National Park Service Geoscientists-in-the-Parks (GIP) Opportunities

Fall/Winter 2019–2020 GIP Positions to Be Posted 1 May 2019

The NPS GIP program places college students and early career professionals (18–35 years old) in National Park Service units for three months to one year to assist with geology and integrated science projects. This program is a partnership between the National Park Service, the Geological Society of America, and the Stewards Individual Placement Program.

www.geosociety.org/gip

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Get into the Field with These GSA Awards

GSA Field Camp Scholar Award

Who should apply? Undergraduate students
Deadline to apply: 5 April

This year's field award will provide US$2,000 to undergraduate students so they can attend the summer field camp of their choice. These scholarships are based on diversity, economic/financial need, and merit.

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Dalila A. de Jesus

My field camp experience was a very rewarding and empowering one. I'm very grateful for the opportunity I had to be there and be part of such a great course and team. I'm even more thankful for all the generous support from GSA, which surely contributed to the amazing and successful experience I had over the summer.
—Dalila A. de Jesus, 2018 GSA Field Camp Scholar Award Winner

GSA, in cooperation with ExxonMobil, offers two programs to support and encourage field geology. This collaboration has proven very successful; in 2018, hundreds of geology students and professors applied for these awards.

GSA/ExxonMobil Bighorn Basin Field Award

Who should apply? Undergraduate and graduate students and faculty
Deadline to apply: 5 April
Camp dates: 5–12 August 2019

This award is a one-week field seminar that offers 20 undergraduate and graduate students and five faculty members a high-quality educational experience in the spectacular Bighorn Basin of north-central Wyoming. The course is free to accepted participants, and all transportation, meals, and living expenses are covered.

The Bighorn Basin Field Award was a great opportunity to learn about both basic oil and gas exploration concepts and what companies value in terms of student field knowledge and experiences. The course has resulted in me redesigning/focusing my own courses to the types of concepts/approaches that were covered and provided a great networking opportunity for students/faculty and industry professionals.
—Brian Currie, 2011 GSA/ExxonMobil Bighorn Basin Field Faculty Award Winner

The Bighorn Basin Field Course has played a big part in my career development to this point. It provided valuable exposure to geoscience in the oil and gas industry and to geoscience field work, exploratory basin analysis, well log interpretation, stratigraphic principles, and petroleum systems, all of which have been valuable skills I have relied on in both technical work and interview settings.
—Hamilton Goodner, 2015 GSA/ExxonMobil Bighorn Basin Field Award Winner

GSA/ExxonMobil Field Camp Excellence Award

Who should apply? Anyone, but the award must be used toward field camp operations
Deadline to apply: 5 April

One field camp instructor/director will receive an award of US$10,000 to assist with his or her summer field season. This award will be based on safety awareness, diversity, and technical excellence.

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To apply for these awards, go to **https://bit.ly/2AL9fKI.** Students and recent graduates must submit an online application form, two letters of recommendation, and a cover letter. *Questions?* Contact Jennifer Nocerino, jnocerino@geosociety.org, +1-303-357-1036.

Recent Minority Student Scholarship recipients. From left to right: David Davis, Lisa Duong, and Nora Soto Contreras.

GSA Minority Student Scholarships

Application deadline: 15 May

Undergraduate students from minority backgrounds are encouraged to apply for a US$1,500 scholarship. Qualified applicants must be U.S. citizens studying at an accredited university or college in one of GSA's regional sections (including Canada and Mexico). Up to six students will be awarded, along with complimentary GSA student membership and meeting registration for this year's GSA Annual Meeting & Exposition (22–25 Sept. in Phoenix, Arizona, USA). Email questions to awards@geosociety.org. Learn more at **http://bit.ly/2Du9z2S.**

On To the Future Travel Awards

- 76% of applicants awarded grants
- Average award US$510
- Applications accepted 1 March–31 May

Join more than 500 students who have received travel funding to attend their first GSA Annual Meeting. On To the Future (OTF) will provide funding to students from diverse backgrounds to attend the GSA 2019 Annual Meeting & Exposition in Phoenix, Arizona, USA, on 22–25 Sept. Awardees will be paired with mentors and have opportunities to interact with GSA leadership. Check the OTF website at **www.geosociety.org/GSA/OTF** for eligibility guidelines and application information. GSA encourages low-income, minority, first-generation, non-traditional, women, veterans, LGBTQ, and students with disabilities to apply.

Thinking about Your Geoscience Career Path? The AGI Student Exit Survey Can Help You Make Informed Decisions

Tahlia Bear, *GSA Diversity and Careers Officer*

Making choices about career pathways is an important decision point for many students. Struggling with questions around whether to attend graduate school, which job sectors are hiring, what skills are sought by employers, and what starting salary should be expected is common. A resource that can help students make informed decisions about these topics is the American Geosciences Institute's (AGI) webinar, "Update on AGI's Geosciences Student Exit Survey Results" (30 Nov. 2018). A recording of this webinar is online at **www.americangeosciences.org/workforce/webinars/update-agis-geoscience-student-exit-survey-results.**

Started in 2013, the annual student exit survey analyzes responses from undergraduate and graduate students who are completing their degrees in the geosciences. The webinar focused on data spanning the past five years and offered some general advice to students, faculty, and practitioners interested in the geoscience workforce outlook.

1. Build a Stronger Quantitative Skill Set

Employers seek students who have a foundation in higher-level quantitative mathematics courses. Taking classes such as linear algebra, differential equations, computational methods, and statistics will help students better analyze work in a professional environment. Based on the exit survey, students at the master's and Ph.D. levels are more likely than undergraduate students to take these classes.

2. Seek Internship Experiences

Internships are critical to building skills that will be used throughout one's career and to gaining understanding of the day-to-day jobs of geoscientists. They also potentially provide an open door to a job after graduation. Surprisingly, more than 60% of undergraduate students do not have internship experience. In many instances, students are not even applying for these opportunities. At the graduate degree levels, most master's students have had at least one internship, while most Ph.D. students have not had any. For all students and at all levels, having one or more internships is advisable.

3. Know Which Job Sectors Are Hiring

The geoscience job market fluctuates, and being aware of these changes and where students are finding jobs after graduation can help determine where to begin the job search. According to the AGI survey, the average time it took for a student to find a job was 2.3 months. The top job sectors hiring those with bachelor's degrees were environmental services and the federal government. For students with a master's degree, it was oil and gas and the federal government. Ph.D. students were being hired more often by four-year universities and research institutes.

4. Consider Starting Salaries

Data on salaries provide direction on what one might expect upon graduation and help determine starting points in salary negotiations. For the majority of students graduating with a bachelor's degree, the salary is between US$30,000 and US$40,000 a year. Those graduating with a master's degree make between US$40,000 and US$110,000, with the majority in the US$50,000 and US$60,000 range. Higher salary levels are mainly due to positions taken in the oil and gas sector. For students graduating with Ph.D.s, the majority of salaries range between US$40,000 and US$50,000.

5. Build Professional Skills

Employers are looking at hiring individuals who not only have strong technical expertise and research and internship experience, but who excel in communication, writing, and time and project management as well. Having one or more internships will help develop these necessary skills.

The best decision making comes from those who are the most informed, and the workforce data gathered by AGI can help. Making choices about a career path does not need to be daunting, and the more data and information you have, the better. To learn more about career planning and exploration, attend one of GSA's GeoCareers workshops, which are offered at each GSA Section Meeting (see **www.geosociety.org/Sections**).

Resources

- Full recording of the AGI webinar: **www.americangeosciences.org/workforce/webinars/update-agis-geoscience-student-exit-survey-results**
- AGI Workforce Currents: **www.americangeosciences.org/workforce/currents**
- Tips for finding internships/employment: **www.geosociety.org/documents/gsa/careers/Tips_Internship_Employment.pdf**
- Suggested coursework, degree requirements, and/or experience: **www.geosociety.org/documents/gsa/careers/Coursework_Requirements.pdf**
- Interviewing tips or strategies to help students get hired: **www.geosociety.org/documents/gsa/careers/Interviewing_Tips.pdf**

The Geological Society of America®

GEOCAREERS

2019 GeoCareers Section Meeting Programs

Geoscience Career Workshops

Part 1: Career Planning and Informational Interviewing: Your job-hunting process should begin with career planning, not when you apply for jobs. This workshop will help you begin this process and will introduce you to informational interviewing. This section is highly recommended for freshmen, sophomores, and juniors. The earlier you start your career planning, the better.

Part 2: Geoscience Career Exploration: What do geologists in various sectors earn? What do they do? What are the pros and cons of working in academia, government, and industry? Workshop presenters and professionals in the field will address these issues.

Part 3: Cover Letters, Résumés, and CVs: How do you prepare a cover letter? Does your résumé need a good edit? Whether you are currently in the market for a job or not, learn how to prepare the best résumé possible. You will review numerous examples to help you learn important résumé dos and don'ts.

Mentor Programs

Enjoy a free lunch while meeting with geoscience mentors working in applied sectors. The popularity of these programs means that space is limited, so plan to arrive early, because lunch is first-come, first-served.

Northeastern Section, Portland, Maine, USA
Mann Mentors in Applied Hydrology Luncheon: Sunday, 17 March
Shlemon Mentor Luncheon Program: Monday, 18 March

Joint Section Meeting (Rocky Mountain, South-Central, North-Central), Manhattan, Kansas, USA
Shlemon Mentor Luncheon Program: Monday, 25 March
Mann Mentors in Applied Hydrology Luncheon:
Tuesday, 26 March

Southeastern Section, Charleston, South Carolina, USA
Shlemon Mentor Luncheon Program: Thursday, 28 March
Mann Mentors in Applied Hydrology Luncheon: Friday, 29 March

Cordilleran Section, Portland, Oregon, USA
Shlemon Mentor Luncheon Program: Wednesday, 15 May
Mann Mentors in Applied Hydrology Luncheon: Thursday, 16 May

For more information, contact Jennifer Nocerino at jnocerino@geosociety.org.

THE GEOLOGICAL SOCIETY OF AMERICA®

Melanie R. Thornton

Hill Essentials for Science Policy: Data, Communication, Relationships, and Kindness

After spending the past year working in the office of Senator Tom Udall (D-NM), my fellowship has come to an end. I am making the transition from Capitol Hill to the environmental non-governmental organization community, taking a position at Defenders of Wildlife as a senior government relations representative. I want to share my personal perspective of what I have learned during my time as a Congressional Science Fellow on Capitol Hill. Here are a few of my takeaways.

Science, Facts, and Data Matter

In an era where "fake news" and "alternative facts" are common, I was comforted by the fact that science and evidence are used by congressional staff when developing policy, analyzing legislation, and advising members of Congress. As a congressional fellow, I have had direct experience working with scientists to understand the impacts on the ground of the recently introduced bill, the Wildlife Corridors Conservation Act (S. 3715). During the process of drafting and analyzing the legislation, congressional staff made legislative recommendations that were informed by data and other scientific information. It is important to remember when providing research and scientific material to congressional staff to be clear and concise. I also learned that while many congressional staff may not be trained scientists, they certainly have a capacity for scientific tenacity.

Get to the Point, and Quickly

Time is an extremely valuable and very limited resource on the Hill. As a staffer, being an effective communicator is, I would argue, the most important part of the job. I quickly learned and got a lot of practice distilling complex scientific issues into one simple paragraph. And sometimes it would require further refinement to just one sentence. This was also applicable to verbal communication, and since time is limited, conveying key takeaways in a short (30 seconds or fewer) elevator speech is an essential skill. As a scientist, my trick was using what I call the "grandparent check"—I often asked myself, "Would my grandparents understand this information?" We live in a communication age, and it is important that we spend the time necessary to develop and refine these skills.

Relationships and Collaboration Make a Difference

The old adage, "It's not what you know, but who you know," especially runs true on the Hill. Effective legislative staffers know the importance of building and maintaining relationships with key staff, stakeholders, and constituents. These relationships provide fertile ground for building strong congressional partnerships and working across the aisle. Under the direction of the member of Congress, it often comes down to congressional staff working together to craft legislation with common-sense solutions. I am a firm believer that a collaborative and cooperative staff is fundamental to bipartisanship and getting legislation and initiatives across the finish line.

Be Kind, Always

To many, walking around the "Capitol Complex," a group of about a dozen buildings and facilities used primarily by the legislative branch of the federal government, may seem daunting. You never know whose path you are going to cross. You could be riding a subway car with a member of Congress or walking the halls with cabinet-level officials. An intern may work his or her way up to become a legislative director or political appointee. These examples demonstrate the value of being kind. And it is an important reminder that especially rings true on Capitol Hill. It is a small world after all.

This manuscript is submitted for publication by Melanie R. Thornton, 2017–2018 GSA-USGS Congressional Science Fellow, with the understanding that the U.S. government is authorized to reproduce and distribute reprints for governmental use. The one-year fellowship is supported by GSA and the U.S. Geological Survey, Department of the Interior, under Assistance Award Number G16AP00179. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government. *Thornton has concluded her fellowship in the office of Senator Tom Udall (D-NM), and will be working at Defenders of Wildlife, as a senior government relations representative, and can be contacted by e-mail at thorntonmelanie4@gmail.com or mthornton@defenders.org.*

THE GEOLOGICAL SOCIETY OF AMERICA

Thompson FIELD FORUMS

REPORT

Processes Controlling the Growth and Evolution of Continental Batholiths, Coast Mountains, British Columbia, Canada

Terrace, British Columbia, Canada
12–17 August 2018

CONVENERS

Harold Stowell, *Geological Sciences, University of Alabama, Tuscaloosa, Alabama, 35487-0338, USA, hstowell@ua.edu*
Margaret Rusmore, *Dept. of Geology, Occidental College, Los Angeles, California 90041, USA, rusmore@oxy.edu*
Glenn Woodsworth, *Geological Survey of Canada, Vancouver, British Columbia V6B 5J3, Canada, tricouni@telus.net*

INTRODUCTION

This Thompson Field Forum brought together 27 geoscientists in Terrace, British Columbia, Canada, to discuss the processes responsible for production of batholiths in continental magmatic arcs. The forum focused on how the existing petrologic, geochronologic, and structural data for the Coast Mountains batholith can inform modern paradigms for batholith growth and magma genesis. Decades-old models based on a robust but limited dataset along the well-exposed Skeena River corridor between Terrace and Prince Rupert provide a unique opportunity to test modern orogenic models using new techniques and expanded datasets.

OVERVIEW

The forum introduced participants to the spectacular geology along the Skeena transect across the British Columbia Coast Mountains and focused attention on areas where future study may resolve outstanding questions. We began with an informal Sunday night meeting at the Thornhill Pub in Terrace, continued by exploring the low-grade Intermontane terrane rocks along the eastern flank of the Coast Mountains batholith on Monday, examined the Central Gneiss Complex and associated plutons on Tuesday, utilized bus and helicopter to access the high-grade rocks of the Central Gneiss Complex on Wednesday, boarded a boat in order to access islands in the western metamorphic belt on Thursday, and returned to the bus for stops in the Ecstall pluton on Friday. This final day of the forum for most of the group ended with dinner and an organized discussion on the current state of knowledge and future research directions for research on batholith growth and evolution. Twelve of the group stayed an additional day and used vans on Saturday for a long trip north to board helicopters and fly to the Seabridge Gold KSM property. We were treated to a spectacular look at porphyry copper mineralization freshly exposed by retreating ice along the eastern flank of the Coast Mountains batholith.

SUMMARY OF EXISTING DATA

The Coast Mountains batholith includes 170 to 45 Ma plutons that vary from gabbro to leucogranite that intruded host rocks from two composite terranes (e.g., Cecil et al., 2018). These rocks have provided stimulus for numerous geological research and mapping projects, including the pioneering maps produced by the Geological Survey of Canada, particularly by the late W.W. Hutchison (1982) and J.A. Roddick (1970). These maps delineated the fundamental contacts for the Coast Mountains batholith and the tectonostratigraphic framework that the plutons intruded. The maps served as the foundation for decades of research, led chiefly by Lincoln Hollister and Maria Crawford, who guided numerous projects with students, post-docs, and other colleagues. Their work led to fundamental advances in knowledge of granulite metamorphism, crustal thickening during batholith growth, the production of batholith melts, and collapse of thickened crust during the last stages of batholith growth.

Geological (e.g., Crawford et al., 1987) and geophysical studies (e.g., Morozov et al., 1998) outline the crustal architecture of the Coast Mountains batholith near Terrace–Prince Rupert. This architecture includes a fundamental offset of the Moho and prominent structural break known as the Coast shear zone. West of this shear zone, the crust averages ~26 km in thickness and includes rocks of the Insular superterrane, which includes the Alexander, Yukon-Tanana, and Wrangellia terranes. East of this shear zone, the crust averages 30 km in thickness and includes rocks of the Intermontane superterrane, here primarily Stikinia. Jurassic and Early Cretaceous plutons occur across the batholith and may represent disparate arcs. By mid-Cretaceous time, however, a single eastward migrating arc was established (Gehrels et al., 2009). The Late Cretaceous core of the batholith is east of the Coast shear zone and includes numerous plutons and the granulite facies rocks of the Central Gneiss Complex. Pioneering work on this granulite delineated the early high P and T conditions and the partial melt reactions in the Central Gneiss Complex, which was rapidly exhumed during the Eocene (Hollister, 1982). Partial melting in the Central Gneiss Complex was synchronous with intrusion of large plutons (e.g., Kasiks Sill), which include both mantle and crustal signatures. Rapid exhumation of the Central Gneiss Complex is interpreted to have been accommodated by top-to-the-east detachment faults between about 55 and 50 Ma. The Shames River detachment is the structurally lowest and most significant shear zone of this system. This detachment

Left: Field Forum participants pose on rocks of the Western Metamorphic Belt. Right: Lincoln Hollister imparts his enthusiasm about rocks in the Coast Mountains batholith. Photos by Chris Mattinson.

juxtaposes high-grade metamorphic rocks of the Central Gneiss Complex with greenschist facies rocks of Stikinia. Higher in the detachment system, rocks within Stikinia are cut by both high- and low-angle normal faults. Evidence of this extensional faulting is largely lacking in areas to the north and south. Forum participants examined the main elements of this complex orogen and participated in lively discussion of existing models, fundamental questions regarding batholith growth in general, and the central Coast Mountains batholith in particular, and directions for future work. Some of these thoughts are summarized in the following section and may help guide future researchers to use the Coast Mountains batholith to address key questions about crustal evolution at convergent margins.

QUESTIONS ABOUT BATHOLITH GROWTH AND EVOLUTION

Batholiths are the exhumed roots of magmatic arcs and contain evidence of the processes that form continental crust. These processes and those related to batholith evolution continue to pose several problems in modern geology. Some of these questions, discussed during the forum, follow.

1. *What are the processes and conditions responsible for the observed temporal and spatial variations in magmatism?*

Gehrels et al. (2009) and Cecil et al. (2018) document the timing of intrusion along more than 1000 km of the Coast Mountains batholith. The data demonstrate both the across-strike variation and the episodic nature of magmatism. In addition, Cecil et al. (2018) document that brief high flux events (HFE) vary temporally along the strike of the Coast Mountains batholith. Future work is needed to associate these HFE with specific crustal and mantle processes.

2. *What processes are responsible for the structural framework of the Coast Mountains batholith during batholith growth, and how did these processes affect magmatism?*

Late Cretaceous crustal thickening is best demonstrated by metamorphic *P-T-t* paths from the Western Metamorphic Belt along the western flank of the Coast Mountains batholith and the Central Gneiss Complex. The structural and tectonic framework for this event is not well understood. Thrust faulting likely played a significant role, especially within the Central Gneiss Complex, but its cause and relation to proposed strike-slip faulting remains uncertain. Similarly, whether the prominent crustal break currently marked by the 65–55 Ma Coast shear zone was the locus of older strike-slip faulting is unknown. The final stage of batholith construction at this latitude was marked by crustal extension in the early Tertiary; the apparent lack of this crustal collapse along strike in the batholith leaves open questions regarding the significance of extension in batholith evolution, the driving forces of extension, and the tectonic framework of the Coast Mountains batholith in early Tertiary time.

3. *What are the causal relationships between magma generation, deformation, and metamorphism?*

Voluminous plutons in the Coast Mountains result in limited preservation of metamorphic rocks. Thus, it is difficult to evaluate whether metamorphism resulted in partial melting or played a less direct role in HFE. Geochronologic data indicate that some metamorphism was synchronous with ca. 80 Ma HFE within the Coast Mountains batholith. Lu-Hf garnet ages of >100 Ma in the Western Metamorphic Belt (Wolf et al., 2010) indicate that the earliest metamorphism along the western flank of the Coast Mountains batholith preceded HFE. Additional studies are needed to better document the timing of metamorphism within and adjacent to the Coast Mountains batholith and to integrate these events with the structural and tectonics evolution of the batholith.

4. *What is the contribution of sediments to magmatism?*

The limited preservation of metamorphic rocks also makes evaluation of sediment contributions to magma generation difficult. Thus, possible relamination of sediments to the base of the crust may only be evaluated through isotopic and trace element signatures.

5. *What drives magma generation at mid to lower crustal levels (e.g., Kasiks Sill)?*

Plutons within the Central Gneiss Complex contain evidence for

Continued next page…

significant crustal contributions (Hollister and Andronicos, 2006). Additional petrologic and geochronologic research is required to better evaluate the proportion of mantle and crustal contributions and assess the conditions that triggered crustal melting.

FUTURE DIRECTIONS

The conveners are excited by the scientific enthusiasm and knowledge displayed by the participants. The spectacular outcrops led to numerous discussions about the research needed to further our understanding of magma generation and batholith evolution. We look forward to future research addressing the many open questions highlighted by this Thompson Field Forum.

ACKNOWLEDGMENTS

This Thompson Field Forum could not have been held without the generous financial and logistical assistance from the Geological Society of America, James B. Thompson, the National Science Foundation, Seabridge Gold Inc., the University of Alabama, and Occidental College. The Metlakatla First Nation kindly allowed us access to their land on Carr Island.

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https://www.americangeosciences.org/workforce/associates

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE EDITOR OPENINGS FOR 2020

GSA is soliciting applications and nominations for science co-editors with **four-year terms beginning 1 January 2020**. Duties include: ensuring stringent peer review and expeditious processing of manuscripts; making final acceptance or rejection decisions after considering reviewer recommendations; and maintaining excellent content through active solicitation of diverse and definitive manuscripts.

POSITIONS AVAILABLE

GEOLOGY Research interests that complement those of the continuing editors include, but are not limited to: energy geology, engineering geology, geomorphology, neotectonics, paleobotany, paleoceanography, paleoclimatology, paleontology, paleoseismicity, Quaternary geology, sedimentary geology, seismology, soils, stratigraphy, tectonics, volcanology.

GSA BOOKS Editor duties include soliciting high-quality book proposals and ensuring that proper peer review procedures are followed by volume editors. Editors handle the entire peer-review process for authored volumes. The successful candidate will have a wide range of interests and expertise, prior editing experience, and a strong publication record.

LITHOSPHERE Research interests that complement those of the continuing editors include, but are not limited to: geochronology, geodynamics, petrology, Precambrian geology, structural geology, tectonics.

GSA BULLETIN Research interests that complement those of the continuing editors include, but are not limited to: geochemistry, geochronology, geomorphology, mineralogy, paleoclimatology, Quaternary geology, stratigraphy, thermochronology, volcanology.

Note that candidates should not feel they must have expertise in *every* area listed; however, editors will sometimes need to handle papers outside of their main disciplines.

- *Geology* ▸ 3 positions
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- *Lithosphere* ▸ 1 position
- *GSA Bulletin* ▸ 1 position

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- experience with online manuscript systems and the ability to make timely decisions; and
- a sense of perspective and humor.

INTERESTED?

- Submit a curriculum vitae and a letter describing why you (or your nominee) are suited for the position to Jeanette Hammann, jhammann@geosociety.org.

Editors work out of their current locations at work or at home. The positions are considered voluntary, but GSA provides an annual stipend and funds for office expenses. **DEADLINE:** First consideration will be given to nominations or applications received by **29 March 2019**.

FUTURE OPENINGS (terms begin January 2021):
GSA Bulletin (one position), *Geology* (one position), *Lithosphere* (one position), GSA books (one position).

In Memoriam

The Society notes with regret the deaths of the following members (notifications received between 2 Oct. 2018 and 2 Jan. 2019). Memorials to deceased members are published open access at **www.geosociety.org/memorials.** Visit that page for links to information on how to honor someone with a memorial.

Antonio M. Arribas
Salamanca, Spain
Date of death: 27 Mar. 2018

John M. Bird
Ithaca, New York, USA
Date notified: 13 Dec. 2018

Arthur L. Bloom
Ithaca, New York, USA
Date notified: 13 Dec. 2018

Hans Martin Bolli
Zurich, Switzerland
Date notified: 27 Dec. 2018

Don W. Byerly
Knoxville, Tennessee, USA
Date of death: 1 Apr. 2018

Emery T. Cleaves
Cockeysville, Maryland, USA
Date of death: 4 Feb. 2018

Donald Robert Coates
Bradenton, Florida, USA
Date notified: 10 Dec. 2018

James B. Cowart
Tallahassee, Florida, USA
Date of death: 12 Apr. 2018

John C. Crelling
Carbondale, Illinois, USA
Date of death: 27 Sept. 2018

Harry M. Dahl
Georgetown, Texas, USA
Date notified: 16 Nov. 2018

William L. Duggan
Nokomis, Florida, USA
Date notified: 11 Dec. 2018

Thomas E. Eastler
Farmington, Maine, USA
Date of death: 30 Aug. 2018

John William Erickson
Oklahoma City, Oklahoma, USA
Date of death: 14 Dec. 2018

Dolf W. Fieldman
Vero Beach, Florida, USA
Date of death: 10 Sept. 2018

John T. Goodier
Cheyenne, Wyoming, USA
Date of death: 6 Dec. 2018

William J. Hail
Aurora, Colorado, USA
Date of death: 5 Dec. 2018

Warren B. Hamilton
Golden, Colorado, USA
Date of death: 26 Oct. 2018

John D. Harper
Calgary, Alberta, Canada
Date notified: 16 Nov. 2018

Donald M. Hoskins
Harrisburg, Pennsylvania, USA
Date of death: 5 Dec. 2018

John F. Hubert
Windermere, Florida, USA
Date of death: 23 Aug. 2018

George C. Kelley
de Ruyter, New York, USA
Date of death: 9 May 2018

Carroll F. Knutson
Las Vegas, Nevada, USA
Date of death: 23 Aug. 2018

David J. Leveson
Brooklyn, New York, USA
Date notified: 26 Dec. 2018

Cole R. McClure Jr.
San Carlos, California, USA
Date notified: 11 Oct. 2018

John A. Minch
Mission Viejo, California, USA
Date notified: 17 Dec. 2018

Brian J. Mitchell
Saint Louis, Missouri, USA
Date of death: 29 May 2018

Eldridge M. Moores
Davis, California, USA
Date of death: 28 Oct. 2018

Edmund Nosow
Lexington, Kentucky, USA
Date notified: 13 Dec. 2018

Carel Otte
La Canada, California, USA
Date of death: 21 July 2018

Ranard J. Pickering
Arlington, Virginia, USA
Date of death: 29 Oct. 2018

Anthony Rabun
Greensboro, North Carolina, USA
Date notified: 31 Dec. 2018

Richard P. Sanders
Carrollton, Georgia, USA
Date notified: 16 Nov. 2018

Dennis J. Shaffer
Clarion, Pennsylvania, USA
Date of death: 6 Nov. 2018

Eugene M. Shearer
Greenwood Village, Colorado, USA
Date of death: 30 Sept. 2018

Ebraham Shekarchi
Bethesda, Maryland, USA
Date notified: 16 Nov. 2018

Darwin R. Spearing
Fort Collins, Colorado, USA
Date of death: 24 Sept. 2018

Andrew M. Spieker
Glenbrook, Nevada, USA
Date notified: 11 Dec. 2018

John Hugh Spotts
Provo, Utah, USA
Date of death: 11 Apr. 2018

Irving G. Studebaker
Federal Way, Washington, USA
Date of death: 16 Oct. 2018

Atholl Sutherland-Brown
Victoria, British Columbia, Canada
Date notified: 16 Nov. 2018

Richard R. Thompson
Bethlehem, Pennsylvania, USA
Date notified: 28 Dec. 2018

Robert J. Tracy
Blacksburg, Virginia, USA
Date of death: 5 Jan. 2019

Colin R. Ward
Sydney, Australia
Date notified: 7 Dec. 2018

Ronald J. Wasowski
Portland, Oregon, USA
Date notified: 18 Dec. 2018

Florence Robinson Weber
Fairbanks, Alaska, USA
Date notified: 18 Nov. 2018

Johannes Weertman
Evanston, Illinois, USA
Date of death: 13 Oct. 2018

Owen L. White
Toronto, Ontario, Canada
Date of death: 23 June 2018

Ronald E. Wilcox
Friendswood, Texas, USA
Date of death: 14 Nov. 2018

Martha S. Wright
Newtown, Connecticut, USA
Date of death: 21 Nov. 2018

CALL FOR NOMINATIONS

GSA Scientific Division Awards

To learn more about GSA's Division awards, see the January 2019 issue of *GSA Today* at **www.geosociety.org/gsatoday/archive/29/1** (p. 5).

GEOARCHAEOLOGY DIVISION

Richard Hay Student Paper/Poster Award

Nominations due 1 Sept.

Claude C. Albritton, Jr., Award

Nominations due 5 Mar.
Submit nominations to gsa.agd@gmail.com

http://rock.geosociety.org/arch

GEOSCIENCE EDUCATION DIVISION

Biggs Award for Excellence in Earth Science Teaching

Nominations due 15 Mar.
community.geosociety.org/gedivision/awards/biggsaward

HISTORY AND PHILOSOPHY OF GEOLOGY DIVISION

History and Philosophy of Geology Student Award

Nominations due 15 June
Submit nominations to Stephen G. Pollock, secretary/treasurer, stephen.pollock@maine.edu.
community.geosociety.org/histphildiv/awards/student

LIMNOGEOLOGY DIVISION

Israel C. Russell Award

Nominations due 15 Mar.
www.geosociety.org/GSA/Awards/about_Division_Awards.aspx#russell

MINERALOGY, GEOCHEMISTRY, PETROLOGY, AND VOLCANOLOGY (MGPV) DIVISION

MGPV Distinguished Geologic Career Award

Nominations due 31 Mar.

MGPV Early Career Award

Nominations due 31 Mar.
Submit nominations to J. Alex Speer, Mineralogical Society of America, 3635 Concorde Pkwy Suite 500, Chantilly VA, 20151-1110, USA; jaspeer@minsocam.org.

community.geosociety.org/mgpvdivision

PLANETARY GEOLOGY DIVISION

Shoemaker Award

Nominations due in August
community.geosociety.org/pgd/awards/shoemaker

Ronald Greeley Award for Distinguished Service

Nominations due 30 June
community.geosociety.org/pgd/awards/greeley

QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION

Farouk El-Baz Award for Desert Research

Nominations due 1 Apr.
community.geosociety.org/qggdivision/awards/el-baz

Distinguished Career Award

Nominations due 1 Apr.
community.geosociety.org/qggdivision/awards/distinguished-career

SEDIMENTARY GEOLOGY DIVISION

Sedimentary Geology Division and Structural Geology and Tectonic Division Joint Award

Stephen E. Laubach Structural Diagenesis Research Award

Nominations due 1 Apr.
community.geosociety.org/sedimentarygeologydiv/awards/laubach

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Academic and Applied Geoscience Relations Committee

Member-at-Large vacancy (industry-related field) (3-year term; E, M)

This committee is charged with strengthening and expanding relations between GSA members in applied and academic geosciences. As such, it proactively coordinates the Society's effort to facilitate greater cooperation between academia, industry, and government geoscientists.

Qualifications: Committee members must work in academia, industry, or government and be committed to developing a better integration of applied and academic science in GSA meetings, publications, short courses, field trips, and education and outreach programs. Professional interests: environmental & engineering geology, hydrogeology, karst, Quaternary geology & geomorphology, structural geology & tectonics, sedimentary geology. Members must also be active in one or more GSA Scientific Divisions.

Arthur L. Day Medal Award Committee

Two Member-at-Large vacancies (3-year terms; E, T)

This committee selects candidates for the Arthur L. Day Medal.

Qualifications: Members should have knowledge of those who have made "distinct contributions to geologic knowledge through the application of physics and chemistry to the solution of geologic problems." All of the committee's work will be accomplished during the months of February/March. All committee decisions must be made by 1 April.

Bascom Mapping Award Committee

Two Member-at-Large vacancies (industry and government-related fields) (3-year terms; E, T)

This committee selects candidates for the Florence Bascom Geologic Mapping Award. This award acknowledges contributions in published high-quality geologic mapping that led the recipient to publish significant new scientific or economic-resource discoveries, and to contribute greater understanding of fundamental geologic processes and concepts.

Qualifications: Members should be knowledgeable in the field of mapping.

Diversity in the Geosciences Committee

Four Member-at-Large vacancies (industry-related fields) (3-year terms; E, M), one Student Representative (2-year term; E, M)

This committee provides advice and support to GSA Council and initiates activities and programs that will increase opportunities for people of ethnic minority, women, and persons with disabilities and raise awareness in the geosciences community of the positive role these groups play within the geosciences. The committee is also charged with stimulating recruitment and promoting positive career development for these groups.

Qualifications: Members of this committee must be familiar with the employment issues these groups face; expertise and leadership experience in such areas as human resources and education is also desired.

Education Committee

One vacancy: Undergraduate Student Representative (2-year term; B, E, M)

This committee works with GSA members representing a wide range of education sectors to develop informal, pre-college (K–12), undergraduate, and graduate earth-science education and outreach objectives and initiatives.

Qualifications: Members of this committee must have the ability to work with other interested scientific organizations and science teachers' groups.

Geology and Public Policy Committee

Two Member-at-Large vacancies (3-year terms; B, E, M), one Student Representative (2-year term; B, E, M)

This committee provides advice on public-policy matters to Council and GSA leadership by monitoring and assessing international, national, and regional science policy; formulating and recommending position statements; and sponsoring topical white papers. This committee also encourages active engagement in geoscience policy by GSA members.

Qualifications: Members should have experience with public-policy issues involving the science of geology; ability to develop, disseminate, and translate information from the geologic sciences into useful forms for the general public and for GSA members; and familiarity with appropriate techniques for the dissemination of information.

B—Meets in Boulder or elsewhere; **E**—Communicates by phone or electronically; **M**—Meets at the Annual Meeting;
T—Extensive time commitment required during application review period. Terms begin 1 July 2020 (unless otherwise noted).

GSA International

Four vacancies: Three Member-at-Large (4-year terms; E, M), one Student Representative (2-year term; E, M)

Serve as GSA's coordination and communication resources seeking to promote, create, and enhance opportunities for international cooperation related to the scientific, educational, and outreach missions shared by GSA and like-minded professional societies, educational institutions, and government agencies. Build collaborative relationships with Divisions and Associated Societies on international issues and serve as a channel for member generated proposals for international themes.

Joint Technical Program Committee

Two Member-at-Large vacancies: one Paleoclimatology & Paleoceanology and one Precambrian Geology (2-year terms 1 Dec. 2019–30 Nov. 2021; B, E).

Members of this committee help finalize the technical program for GSA's annual meetings by participating in the web-based selection and scheduling of abstracts, as well as topical session proposal review.

Qualifications: Members must be familiar with computers and the web, be a specialist in one of the specified fields, and be available in late July–mid-August for the organization of the annual meeting technical program.

Membership and Fellowship Committee

Two vacancies: One Member-at-Large—Industry (3-year term; B, T), one Student Member-at-Large (3-year term; B, T)

This committee contributes to the growth of the GSA membership, enhances the member experience, and serves a vital role in the selection of Fellows, with the goal of fostering a membership community as pertinent and global as our science. Committee members should understand what various segments of members want from GSA and should be familiar with outstanding achievers in the geosciences worthy of fellowship.

Qualifications: Committee members should have experience in benefit, recruitment, and retention programs.

Nominations Committee

Two Member-at-Large vacancies (3-year terms; B, E)

This committee recommends nominees to GSA Council for the positions of GSA Officers and Councilors, committee members, and Society representatives to other permanent groups.

Qualifications: Members must be familiar with a broad range of well-known and highly respected geoscientists.

North American Commission on Stratigraphic Nomenclature

One Representative (3-year term)

Penrose Medal Award Committee

Two Member-at-Large vacancies (3-year terms; E, T)

Members of this committee select candidates for the Penrose Medal Award. Emphasis is placed on "eminent research in pure geology, which marks a major advance in the science of geology."

Qualifications: Members should be familiar with outstanding achievers in the geosciences worthy of consideration for the honor. All of the committee's work will be accomplished during the months of February and March. All committee decisions must be made by 1 April.

Professional Development Committee

Two Member-at-Large vacancies (3-year terms; E)

This committee directs, advises, and monitors GSA's professional development program; reviews and approves proposals; recommends and implements guideline changes; and monitors the scientific quality of courses offered.

Qualifications: Members must be familiar with professional development programs or have adult education teaching experience.

Public Service Award Committee

One Member-at-Large vacancy (3-year term; E, T)

The purpose of this committee is to generate, receive, and evaluate candidates for the GSA Public Service Award and the AGI Outstanding Contributions to the Public Understanding of the Geosciences Award. These awards are in recognition of outstanding individual contributions to either public awareness of the earth sciences or the scientific resolution of earth-science problems of significant societal concern.

Publications Committee

One vacancy: Geoscience Information Society Library Representative (4-year term; B, E, M)

The primary responsibilities of the committee are nomination of candidates for editors when positions become vacant; reviewing the quality and health of each Society publication; and reporting recommendations to Council for changes in page charges, subsidies, or any other publishing matter on which Council must make a decision. To carry out this charge, headquarters will provide the committee with all necessary financial information.

Research Grants Committee

Twelve Member-at-Large vacancies with various specialties (3-year terms; B, E, T)

The primary function of this committee is to evaluate the research grant applications received, by delegation of the Council's authority and within the limits of the research grants budget, to award specific grants to chosen recipients. The committee will also act on the distribution of funds derived from any other gifts or memorial or award funds that are to be administered by it.

Qualifications: Members should have experience in directing research projects and in evaluating research grant applications. **Extensive time commitment required 15 Feb.–15 Apr.**

Young Scientist Award (Donath Medal) Committee

Three vacancies: Two Members-at-Large, one Councilor/ former Councilor (3-year terms; E, T)

Committee members investigate the achievements of young scientists who should be considered for this award and make recommendations to GSA Council.

B—Meets in Boulder or elsewhere; **E**—Communicates by phone or electronically; **M**—Meets at the Annual Meeting;
T—Extensive time commitment required during application review period. Terms begin 1 July 2020 (unless otherwise noted).

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Qualifications: Members should have knowledge of young scientists with "outstanding achievement(s) in contributing to geologic knowledge through original research which marks a major advance in the earth sciences." All of the committee's work will be accomplished during the months of February and March. All committee decisions must be made by 1 April.

Committee, Section, and Division Volunteers: Council Thanks You!

GSA Council acknowledges the many member-volunteers who, over the years, have contributed to the Society and to our science through involvement in the affairs of the GSA. Your time, talent, and expertise help build a solid and lasting Society.

Miss Those Rock Stars Articles?

Marie Tharpe

Submit a Story!

These two-page life stories of Rock Star geologists (read them all at **www.geosociety.org/gsatoday/RockStars.htm**) have enlivened *GSA Today's* pages for years, but we haven't had a new article since 2017. If you would like to submit a brief life story of a Rock Star geologist, see GSA's History & Philosophy of Geology Division's guidelines at **https://bit.ly/2QCEHqA.**

Elections: GSA Officers and Councilors

GSA Elections Open on 14 March 2019

GSA's success depends on you—its members—and the work of the officers serving on GSA's Executive Committee and Council.

Members will receive instructions for accessing an electronic ballot via our secure website, and biographical information on the nominees will be online for review at that time. Paper versions of both the ballot and candidate information will also be available upon request.

Please help continue to shape GSA's future by voting on these nominees. The election will open for voting on 14 March 2019. To be included in the count, ballots must be submitted electronically, faxed to GSA Headquarters (+1-303-357-1070), or postmarked before midnight on **13 April 2019.**

2019 Officer Nominees

PRESIDENT
(July 2019–June 2020)

Donald I. Siegel
Syracuse University
Syracuse, New York, USA
We congratulate our incoming president!

PRESIDENT-ELECT | PRESIDENT
(July 2019–June 2020)
(July 2020–June 2021)

J. Douglas Walker
University of Kansas
Lawrence, Kansas, USA

TREASURER
(July 2019–June 2020)

Richard C. Berg
Illinois State Geological Survey
Champaign, Illinois, USA

2019 Council Nominees

COUNCILOR POSITION 1
Divisions Liaison
(July 2019–June 2023)

Steven Driese
Baylor University
Waco, Texas, USA

Glenn Thackray
Idaho State University
Pocatello, Idaho, USA

COUNCILOR POSITION 2
(July 2019–June 2023)

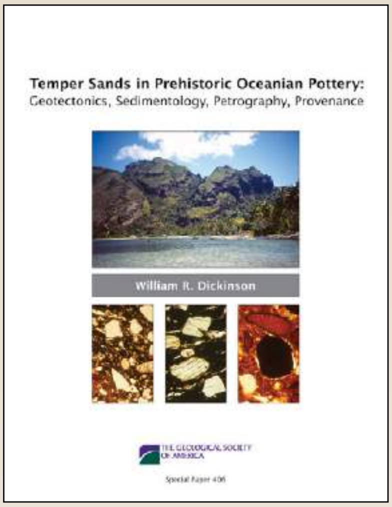
Margaret Eggers
Eggers Environmental, Inc.
Oceanside, California, USA

Harvey Thorleifson
University of Minnesota
Minnesota Geological Survey
Minneapolis, Minnesota, USA

COUNCILOR POSITION 3
(July 2019–June 2023)

Julia Baldwin
University of Montana
Missoula, Montana, USA

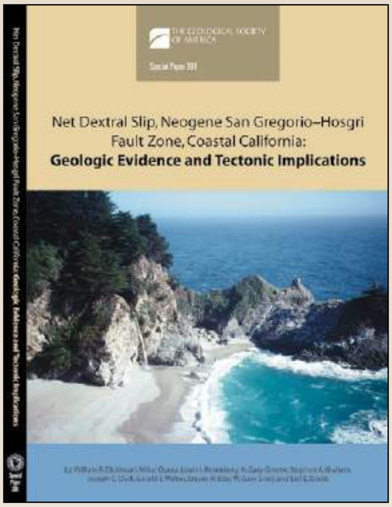
Katharine Huntington
University of Washington
Seattle, Washington, USA



Temper Sands in Prehistoric Oceanian Pottery: Geotectonics, Sedimentology, Petrography, Provenance

By William R. Dickinson

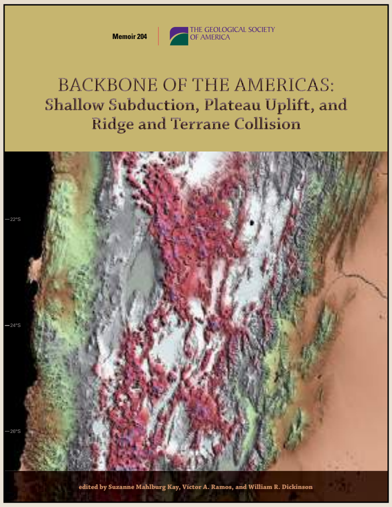
SPE406, ISBN 9780813724065, 160 p., $10.00



Net Dextral Slip, Neogene San Gregorio–Hosgri Fault Zone, Coastal California: Geologic Evidence and Tectonic Implications

By William R. Dickinson, Mihai Ducea, Lewis I. Rosenberg, H. Gary Greene, Stephan A. Graham, Joseph C. Clark, Gerald E. Weber, Steven Kidder, W. Gary Ernst, and Earl E. Brabb

SPE391, ISBN 0813723914, 43 p., $10.00



Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision

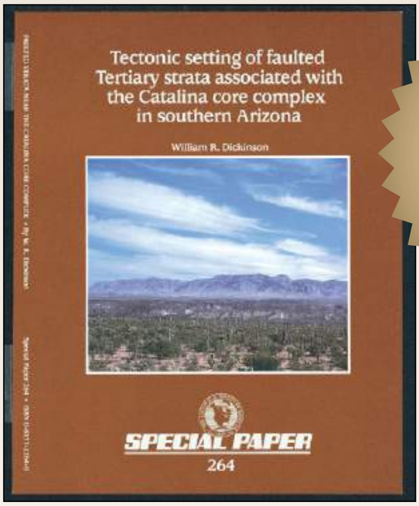
Edited by Suzanne Mahlburg Kay, Víctor A. Ramos, and William R. Dickinson

MWR204P, ISBN 9780813712048, 278 p., $9.99

Kinematics of Transrotational Tectonism in the California Transverse Ranges and Its Contribution to Cumulative Slip Along the San Andreas Transform Fault System

By William R. Dickinson

SPE305P, ISBN 0813723051, 46 p., $9.99



Tectonic Setting of Faulted Tertiary Strata Associated with the Catalina Core Complex in Southern Arizona

By William R. Dickinson

SPE264P, ISBN 0813722640, 106 p., $9.99

EXPLORE plate tectonics, sedimentary geology, the Colorado Plateau, Pacific Oceania geology, and more!

Ads (or cancellations) must reach the GSA advertising office no later than the first of the month, one month prior to the issue in which they are to be published. (Note: Combined March/April issue releases on March schedule). Print ads will also appear on the Geoscience Job Board to coincide with the month of print issue. **Contact: advertising@geosociety.org,** +1-800-472-1988 ext. 1053, or +1-303-357-1053. Email correspondence should include complete contact information (including phone and mailing address). Rates are in U.S. dollars.

Classification	Per Line for 1st month	Per line each addt'l month (same ad)
Positions Open	$9.35	$9.30
Fellowship Opportunities	$9.35	$9.30
Opportunities for Students		
First 25 lines	FREE	$5.00
Additional lines	$5.00	$5.00

POSITIONS OPEN

Assistant Professor of Geology, Dept. of Physics and Geosciences, Texas A&M University–Kingsville

Position: The Department of Physics and Geosciences at Texas A&M–Kingsville invites applications for a tenure track Assistant Professor position with research and teaching focus in Mineralogy-petrology or structural-field geology. The position will begin in August 2019. Review of applications will begin on February 15 and will remain open until filled.

Job Description: Primary responsibilities will be to teach a six-course load over the academic year; to develop a creative, externally funded research program; to co-manage the department's annual summer field camp; and to provide service to the University, profession, and community. Semester teaching assignments include 1–2 core class and 2–3 introductory service classes. A more complete job description may be found at https://tamus.wd1.myworkdayjobs.com/TAMUK_External.

Minimum Qualifications: Candidates must have PhD in Geology, Earth Sciences, or a related field from a regionally accredited institution or university. Expertise to teach courses in either (1) Mineralogy, Geochemistry, and Igneous/Metamorphic Petrology, or (2) Field Geology, Geomorphology, and Structural Geology. Candidates should have strong field skills.

All positions are security-sensitive. Applicants are subject to a criminal history investigation, and employment is contingent upon the institution's verification of credentials and/or other information required by the institution's procedures, including the completion of the criminal history check.

Equal Opportunity/Affirmative Action/Veterans/Disability Employer committed to diversity.

Geology Instructor Position, Dept. of Earth Sciences, The University of South Alabama

The University of South Alabama Earth Sciences Department invites applications for a full-time, 12-month, non-tenure-track faculty Instructor position, starting August 15, 2019. Candidates with outstanding geology teaching credentials are particularly encouraged to apply. Minimum qualifications are a M.S. degree in Geology or related discipline at the time of appointment. Review of applications will begin March 1st, 2019, and will continue until the position is filled.

For more information, please see the following link: http://www.southalabama.edu/colleges/artsandsci/earthsci/geology/.

The University of South Alabama is an EO/AA Employer—minorities/females/veterans/disabilities/sexual orientation/gender identity.

GSA FOUNDATION Update

John W. (Jack) Hess, *GSA Foundation President*

"Field experiences in all aspects of the geosciences are essential."

These words from Jinny Sisson, instructional professor at the University of Houston and director of the Yellowstone-Bighorn Research Association (YBRA) Field Camp, underscore a crucial facet of GSA's mission—to enrich the geosciences through cultivating and supporting aspiring geoscientists, particularly by enabling field opportunities. Through the Field Camp Opportunities Fund, GSA members can aid the Society in fulfilling this mission and help shape the future of geoscience.

Throughout her career, both as a field instructor and field camp director, Jinny has been a passionate advocate for student field experiences. In the field, students come to fully understand concepts that were taught in the classroom, an experience Jinny describes as invaluable for students and instructors alike. Students learn essential geoscientific skills, such as geologic field mapping and field safety, while expanding basic skills, such as common-sense decision making and teamwork. These experiences help broaden students' backgrounds and skillsets, allowing them to discover their interests, as well as preparing them for careers in academia, the petroleum and environmental industry, or even outside of the geosciences altogether.

This was true for Amy Moser, a Ph.D. candidate at the University of California Santa Barbara and 2013 YBRA attendee, whose field camp experience was life changing:

> There's not a day that goes by that I don't think about how field camp laid the foundation for my career in the geosciences. I remember sitting with my mapping partners during one of our last projects, looking out across the half-graben we were mapping, and in that moment knowing that geology was what I wanted to do for the rest of my life. Beyond solidifying my career choice, my time at YBRA taught me skills that I continue to use both in my own field research and when I teach in the field. Teaching in the field has been the most rewarding part of my career in geology thus far, which is an experience I wouldn't have if it weren't for those fundamental days at YBRA. Field camp is where everything comes together for undergraduates in the geosciences.

However, while the importance of fieldwork is significant, costs force many students to forgo this critical experience. Costs impact field camp directors as well. As Jinny notes, "We still use mostly pencil and paper mapping techniques due to financial considerations about incorporating digital techniques with a population of students who can barely afford the extra expense of a field course. We've had students delay attending field camp for over three years because they don't have the money to attend. There needs to be more support for field geology programs not just for students but for young faculty wanting to share their knowledge about how the Earth works."

Will you join us in giving students like Amy the support they need to explore the field and discover their passions? GSA's Field Camp Opportunities Fund allows GSA to provide financial support for aspiring geoscientists so they can hone their field skills and discover their interests without financial strain. **Make your gift today!** You can give online at **gsa-foundation .org/donate.** To discuss in-depth ways that you can support field camp scholarships, please contact Debbie Marcinkowski at +1-303-357-1047 or dmarcinkowski@geosociety.org.

Left: Amy Moser at the Beartooth Mountains during the 2013 YBRA field camp. Right: Moser at Clarks Fork Canyon in northern Wyoming.

www.gsa-foundation.org

GROUNDWORK

Furthering the Influence of Earth Science

The AGeS2 (Awards for Geochronology Student research 2) Program: Supporting Community Geochronology Needs and Interdisciplinary Science

Rebecca M. Flowers, *Dept. of Geological Sciences, University of Colorado Boulder, Boulder, Colorado 80309, USA;* ***J Ramón Arrowsmith,*** *Arizona State University, School of Earth & Space Exploration, Tempe, Arizona 85287, USA;* ***Vicki McConnell,*** *Geological Society of America, 3300 Penrose Place, Boulder, Colorado 80301, USA;* ***James R. Metcalf,*** *Dept. of Geological Sciences, University of Colorado Boulder, Boulder, Colorado 80309, USA;* ***Tammy Rittenour,*** *Dept. of Geology, Utah State University, Logan, Utah 84322, USA; and* ***Blair Schoene,*** *Dept. of Geosciences, Princeton University, Princeton, New Jersey 08544, USA*

THE INCREASING GEOCHRONOLOGY DATA AND EDUCATION NEEDS OF THE EARTH-SCIENCE COMMUNITY

Geochronology is essential in the geosciences. It is used to resolve the durations and rates of earth processes, as well as test causative relationships among events. Such data are increasingly required to conduct cutting-edge, transformative, earth-science research. The growing need for geochronology is accompanied by strong demand to enhance the ability of labs to meet this pressure and to increase community awareness of how these data are produced and interpreted. For example, a 2015 National Science Foundation (NSF) report on opportunities and challenges for U.S. geochronology research noted: "While there has never been a time when users have had greater access to geochronologic data, they remain, by and large, dissatisfied with the available style/quantity/cost/efficiency" (Harrison et al., 2015, p. 1). And the 2012 National Research Council NROES (New Research Opportunities in the Earth Sciences) report (Lay et al., 2012, p. 82) recommended: "[NSF] EAR should explore new mechanisms for geochronology laboratories that will service the geochronology requirements of the broad suite of research opportunities while sustaining technical advances in methodologies." The AGeS (Awards for Geochronology Student research) program is one way that these calls are being answered.

THE AGeS1 PROGRAM: A COLLABORATIVE STRATEGY FOR SUPPORTING COMMUNITY GEOCHRONOLOGY NEEDS

The AGeS program is a collaborative strategy for supporting access to geochronology data and expertise. The goals of AGeS are to (1) broaden access to geochronology; (2) educate users of geochronology data; (3) promote synergistic science by fostering new relationships between labs, students, and scientists in different disciplines; and (4) provide strategic, high-quality, scientifically valuable geochronology data for projects in which both users and producers of the data are intellectually engaged. The AGeS program offers support of up to US$10,000 (typical awards ~US$8,500) for graduate students to visit an AGeS lab for a week or more, participate in sample preparation and analysis, and learn fundamental aspects of the methods, techniques, theory, and interpretational approaches used in modern analytical facilities while being mentored by geochronologists on a project of joint interest. These awards fill an important funding gap between small (US$1,000–US$3,000) student research grant opportunities (e.g., Geological Society of America [GSA] student research grants) and large (>US$100,000) NSF grants, and can be sufficient to acquire a publishable data set, catalyze new collaborations, and provide the foundation for future larger proposals.

AGeS1 was implemented in 2014 within the framework of the NSF EarthScope program (Flowers et al., 2014; Nadin, 2015). Twenty-five graduate students were engaged deeply in AGeS1 by receiving awards of US$5,300 to US$9,500 in 2015, 2016, and 2017 (Fig. 1A). The awards also financed "riskier" science ideas, some of which came to fruition (e.g., Williams et al., 2017). However, the impact of AGeS1 extends far beyond the funded projects. The AGeS1 funding opportunity provided a specific reason for geochronology users to reach out to the data producers annually, amounting to >40–50 contacts each year between students and labs regarding potential collaborative, interdisciplinary research projects. A total of 135 AGeS1 proposals including a diversity of geochronology techniques were submitted over three proposal cycles, each one involving new interactions between labs and students. Even for some unfunded projects, new research proceeded because the proposal-writing process helped focus and articulate the ideas and generated joint enthusiasm for the study. Six geochronology experts (scientists from private and state universities, a small liberal arts college, and a federal agency) dedicated substantial time to reviewing and ranking every submitted proposal, such that all students received feedback on their project ideas.

Between 2014 and 2018, the AGeS lab network grew to include 73 senior scientists associated with 43 labs distributed across the U.S., encompassing a wide range of geochronology methods (Figs. 1B and 1C). Any lab in the U.S. or its

GSA Today, v. 29, https://doi.org/10.1130/GSATG392GW.1.

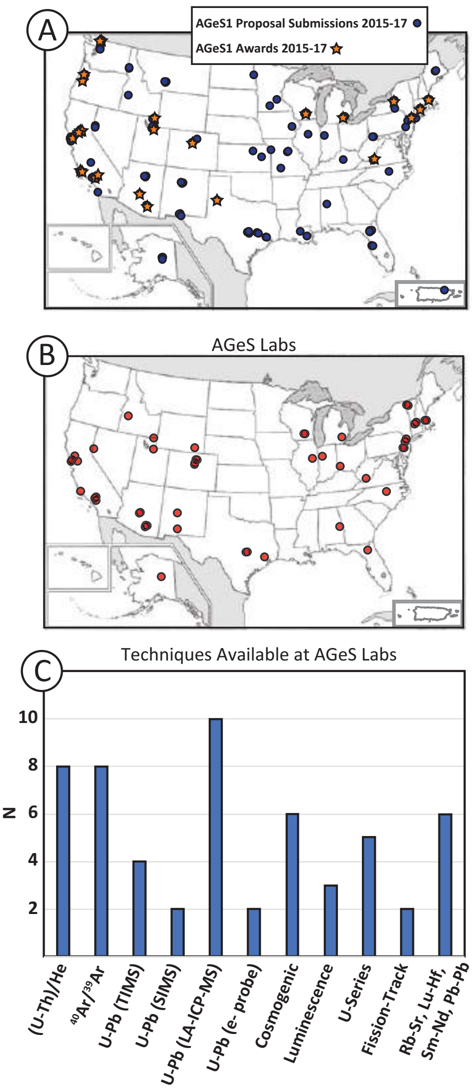


Figure 1. (A) Map showing locations of home institutions of the 135 submitted student proposals over three AGeS (Awards for Geochronology Student research) proposal cycles, along with the funded projects. (B) Map showing locations of the 43 AGeS geochronology labs. (C) Plot of techniques available at AGeS labs. LA-ICP-MS—laser ablation–inductively coupled plasma–mass spectrometry; SIMS—secondary ion mass spectrometry; TIMS—thermal ionization mass spectrometry.

territories can become an AGeS lab by providing a one- to two-page lab profile that is posted on the AGeS lab database webpage (http://www.geosociety.org/GSA/grants/ages2/labs.aspx) to help geochronology users connect with potential host facilities. The lab database only includes facilities that have self-identified as being interested in new collaborations. The lab profiles offer details about analytical costs, sample preparation, realistic time-frames for lab visits, and the education and training experiences provided for visitors. This wealth of information about labs enhances lab accessibility, makes the geochronologists behind the facilities more approachable to the greater user community, and serves as an unprecedented resource for scientists interested in using geochronology regardless of their relationship to the grant program.

THE AGeS2 PROGRAM: AN EXPANDED INITIATIVE

Motivated by widespread support for AGeS1, new cross-programmatic funding from NSF has now built AGeS2 into a wider initiative. AGeS2 expands its purview beyond the primarily North American–based focus of the EarthScope AGeS1 program, to encompass the broader science supported by the Division of Earth Sciences of NSF, which aims at "...improving the understanding of the structure, composition, and evolution of the Earth, the life it supports, and the processes that govern the formation and behavior of the Earth's materials" (NSF-GEO website). AGeS2 has double the annual award funding of AGeS1, and thus expects to support a total of 54–60 graduate student geochronology projects (18–20 per year) over three award cycles in 2019, 2020, and 2021. The outcome will be a broader suite of users, AGeS labs, and types of science that receive funding. A new partnership with GSA is enabling successful management of this effort.

AGeS2 will also take advantage of new opportunities for cohort- and community-building afforded by the program's popularity to maximize the educational and scientific outcomes of AGeS investments. These activities will include regular teleconferences with each year's AGeS student cohorts and AGeS cohort gatherings prior to the 2020 and 2021 GSA Annual Meetings. Ongoing student–lab-advisor interactions will be encouraged throughout the typical two-year AGeS project duration to further promote project success and publication productivity. We recognize the value of these sustained relationships and expect to characterize their quality and the networks that develop as part of our assessment effort.

For more information about AGeS2, go to www.geosociety.org/ages. As in AGeS1, interested students apply to AGeS2 by first initiating contact with an AGeS lab to discuss a potential project. If the lab feels that the proposed work is mutually beneficial, the lab helps the student refine and clarify the project. Students apply by submitting a project description and detailed budget with justification. Letters of support from the home institution project supervisor and host lab director complete the application.

ACKNOWLEDGMENTS

AGeS2 is supported by NSF EAR-1759200, -1759353, and -1759201 awards to R.M. Flowers, JR. Arrowsmith, and V. McConnell. AGeS1 was supported by NSF EAR-1358514, -1358554, -1358401, and -1358443 awards to R.M. Flowers, JR. Arrowsmith, T. Rittenour, B. Schoene, and J.R. Metcalf. We thank the AGeS1 review panel for their time invested in the proposal evaluation process.

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Manuscript received 17 Oct. 2018
Manuscript accepted 20 Nov. 2018

GSA MEMBERSHIP 2019
Renew or Join at www.geosociety.org/members

REACH NEW HEIGHTS
with your GSA membership benefits

As an AGI member society, GSA members are eligible for a free digital subscription to *EARTH* magazine, published by AGI. Go to **https://digital.earthmagazine.org** to sign up. The planet is at your fingertips for free!

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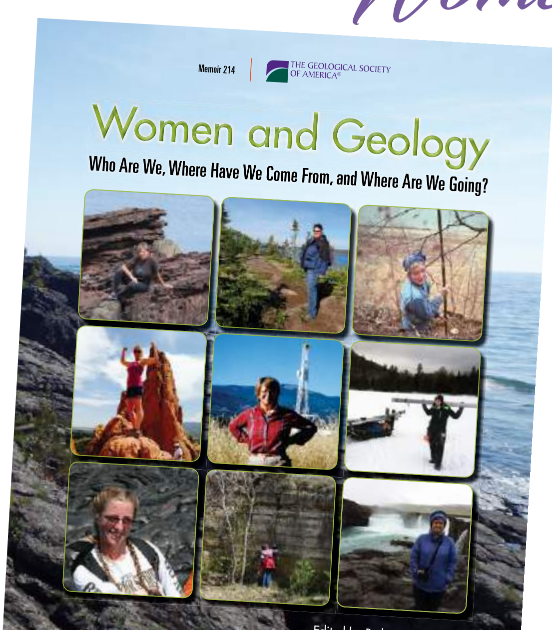
THE GEOLOGICAL SOCIETY OF AMERICA®

New Memoir Recognizes the Achievements of *Women in Geology*



March is Women's History Month, and we're excited to highlight a new GSA memoir that acknowledges the great contributions women have made to the geosciences. Memoir 214, *Women and Geology: Who Are We, Where Have We Come From, and Where Are We Going?*, celebrates the achievements of women in geology through individual stories of remarkable women geoscientists, the challenges they have had to overcome, and the work they have done to advance the role of women in the field. Chapters include the first American women researchers in Antarctica, a survey of Hollywood disaster movies and the casting of women as geologists, social media campaigns such as #365ScienceSelfies, and the stories of the Association for Women Geoscientists and the Earth Science Women's Network and their work to support and mentor women in geology.

Receive 10% off when you purchase this memoir during the month of March. Enter coupon code **WHM10** at checkout.

Get your copy today at http://rock.geosociety.org/store.

2019 GSA Section Meetings

Northeastern

17–19 March
Portland, Maine, USA
Meeting Chair: Steve Pollock, spollock@maine.rr.com
www.geosociety.org/ne-mtg

Joint South-Central/North-Central/ Rocky Mountain

25–27 March
Manhattan, Kansas, USA
Meeting Chairs: Matthew Kirk, matthew.f.kirk@gmail.com; Tina Niemi, niemit@umkc.edu; Shannon Mahan, smahan@usgs.gov
www.geosociety.org/sc-mtg

Southeastern

28–29 March
Charleston, South Carolina, USA
Meeting Chairs: Scott Harris, HarrisS@cofc.edu; Katie Luciano, LucianoK@dnr.sc.gov
www.geosociety.org/se-mtg

Cordilleran

15–17 May
Portland, Oregon, USA
Meeting Chairs: Martin Streck, streckm@pdx.edu; Jim O’Connor, oconnor@usgs.gov
www.geosociety.org/cd-mtg

Northeastern image: Portland waterfront, Portland, Maine, USA. Photo courtesy Maine Office of Tourism. Joint Meeting image: Manhattan, Kansas, USA. Photo courtesy K-State Photo Services. Southeastern image: Beach boardwalk, Charleston, South Carolina, USA. Photo courtesy Meetcharleston.com. Cordilleran image: Chanticleer Point, Portland, Oregon, USA. Photo by Martin Streck.